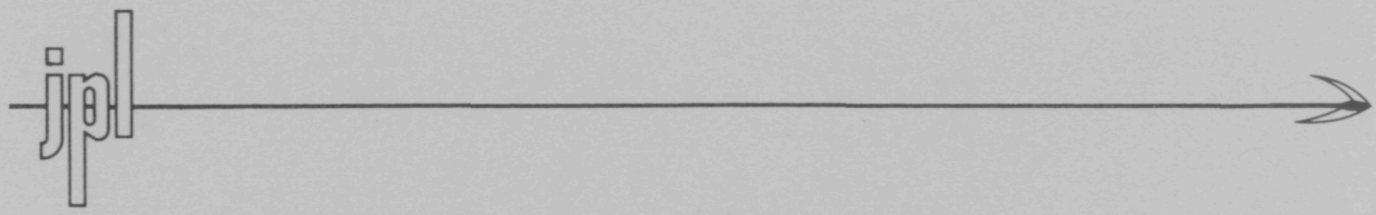
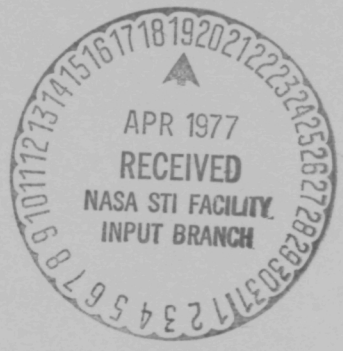


D60-39

[redacted]



JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

(NASA-CR-152720) SCIENCE GROUND DATA SYSTEM AND SCIENCE OPERATIONS ORGANIZATION FOR REMOTELY CONTROLLED LUNAR TRAVERSES. PHASE A: STUDY REPORT (Jet Propulsion Lab.) 158 p
N77-76301
Unclas
00/14 25348

760-39

SCIENCE GROUND DATA SYSTEM AND SCIENCE OPERATIONS ORGANIZATION FOR REMOTELY CONTROLLED LUNAR TRAVERSES

PHASE "A" STUDY REPORT

October 10, 1969

Prepared by: C W B McCormick

C W B McCormick

Approved by: W. F. Eichwald

W F Eichwald
Assistant Section Manager
Space Flight Operations
Section

Approved by: J. D. Burke

J D Burke
Study Leader
Advanced Lunar Studies

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

Page intentionally left blank

Page intentionally left blank

ACKNOWLEDGMENT

Appreciation is expressed to the following, who provided information and advice on the report subject material: Dr R G Brereton, Mr R Choate, Mr R B Coryell, Mr W J Downhower, Mr E A Howard, Dr L D Jaffe, Mr N L Nickle, and Mr W Wolin

Contributors to the report were Mr G H Redmann and Mr N Zafman of JPL, and Mr K A Filetti and Mr R. R Mullen of Hughes Aircraft Company

FOREWORD

This document reflects the output of study efforts in support of the NASA Apollo Lunar Exploration Office by the Advanced Lunar Studies Team in the Operations area Two studies were performed concurrently, one on Navigation and Guidance Operations and the other on Science Operations The Science study is covered in this report, and the Navigation and Guidance study is covered in 760-42 Both studies have been conducted so as to yield information in the form specified by NASA Handbook 7121 2, to support Phased Project Planning

ABSTRACT

This report describes early mission operations planning for the ground support of science operations by a lunar surface-roving vehicle The vehicle's mission is geological and geophysical reconnaissance plus terminal rendezvous with an astronaut Both the vehicle and its science payload will be controlled from Earth The report presents a preliminary functional design of the data processing and organizational elements of the ground system required to support science operations

CONTENTS

Section	Title	Page
I	INTRODUCTION	1-1
	A SUMMARY	1-1
	B OBJECTIVES	1-3
	C SCOPE	1-3
	D STUDY APPROACH	1-4
	E ASSUMPTIONS	1-5
II.	LRV MISSION DESCRIPTION	2-1
	A MISSION OBJECTIVES	2-1
	B. MISSION CONSTRAINTS	2-2
	C THE REMOTELY CONTROLLED SCIENCE MISSION	2-2
	1. Science Goals	2-2
	2 Description of Science Mission	2-2
III	SCIENCE GROUND DATA SYSTEM	3-1
	A. SGDS FUNCTION WITHIN THE MISSION OPERATIONS COMPLEX	3-1
	1 Relation of SGDS to Mission Operations Complex	3-1
	2 Data Subsystems of SGDS	3-3
	B DATA SOURCES	3-3
	C DATA FACILITIES	3-5
	D. MISSION-INDEPENDENT DATA-FUNCTION CAPABILITIES	3-6
	E EXPERIMENTS	3-6
	1. Baseline Experiments	3-7
	2 Baseline Instruments	3-7
IV.	SCIENCE TELEMETRY DATA SUBSYSTEM	4-1
	A. TELEMETRY DATA STREAMS	4-1
	B. DATA FUNCTIONS COMMON TO ALL DATA STREAMS	4-2
	1 Selection	4-2
	2. Data Handling	4-3
	3. Data Distribution	4-4
	4 Data Display	4-4
	5 Data Processing	4-4

CONTENTS (contd)

Section		Title	Page
	C	DATA FUNCTIONS UPON THE SCIENCE DATA STREAM .	4-5
		1 General Science Data Functions	4-5
		2 Diffractometer Data Treatment	4-6
		3. Spectrometer Data Treatment	4-11
		4 Magnetometer Data Treatment	4-12
		5 Gravimeter Data Treatment	4-13
		6 Seismometer Data Treatment	4-14
		7 Sample Handling and Storage Data Treatment	4-15
		8 Sample Inspection Data Treatment	4-16
	D	DATA FUNCTIONS UPON THE IMAGING DATA STREAM	4-17
		1 General Imaging Data Functions	4-17
		2 Panoramic TV Camera Data Treatment	4-18
		3 Foreground TV Camera Data Treatment	4-23
		4 Sample TV Camera Data Treatment .	4-24
		5 Laser Radar Data Treatment .	4-25
	E	DATA FUNCTIONS UPON THE PAYLOAD ENGINEERING DATA STREAM	4-26
		1 General Payload Engineering Data Functions	4-29
		2 Current Instrument Conditions .	4-29
		3. Actual Alarms .	4-30
		4 Data Validity and Adjustment	4-31
		5 Impending Alarm Conditions .	4-31
		6. Optimization of Operating Conditions	4-32
V		SCIENCE COMMAND DATA SUBSYSTEM	5-1
	A	SCIENCE COMMAND DATA SUBSYSTEM FUNCTIONS	5-1
	B	COMMAND DATA STREAMS .	5-2
	C.	OUTBOUND COMMAND DATA STREAM FUNCTIONS . .	5-2
		1 Instructions	5-2
		2 Alarms	5-2
		3 Mission Operations Plan Execution	5-4
		4. Command Sequence Generation	5-4
		5. Command Initiation	5-5
		6 Computer Programs	5-6
	D	INBOUND COMMAND DATA STREAM FUNCTIONS	5-7
		1. Verification and Confirmation	5-7
		2 Execution Check-Value Generation	5-9

CONTENTS (contd)

Section		Title	Page
VI		SCIENCE OPERATIONS ORGANIZATION	6-1
	A	FUNCTIONS OF THE SCIENCE OPERATIONS ORGANIZATION	6-1
		1 Engineering Status of Instruments	6-2
		2 Instrument Use	6-2
		3. Analysis and Interpretation	6-3
		4 Origination of Required Command Functions	6-3
		5 Liaison and Support Functions	6-4
	B	CANDIDATE SCIENCE OPERATIONS ORGANIZATIONS	6-4
		1. Plan A	6-4
		2 Plan B	6-6
VII		PROBLEM AREAS	7-1
	A	MISSION OPERATIONS PLANNING	7-1
		1. Manned Mission Interfaces	7-1
		2 Mission Definition Schedule	7-2
		3 Time-Line Analysis on Rudimentary Level	7-2
		4 Lack of Consideration of Nonstandard Events	7-2
	B	GROUND DATA SYSTEM	7-2
		1 Payload Definition for LRV	7-3
		2 DSN Interface	7-3
		3 Command Traffic	7-3
		4. LRV Performance Analysis Requirements on GDS	7-3
		5 GDS Functional Design Feasibility Not Fully Tested	7-3
	C	MISSION OPERATIONS ORGANIZATION	7-4
		1 Science/Navigation-and-Guidance/Vehicle/Mission Control Real-Time Interfaces	7-4
		2 Science Operations Execution Real-Time Interfaces	7-4
		3 Organizational Flexibility	7-5
		4 Personnel Training	7-5
		5 LRV Vehicle Performance Analysis Organizations	7-5
VIII		IMPLEMENTATION PLAN	8-1
	A.	SCOPE	8-1
	B	BASIC ASSUMPTIONS	8-1
	C	FUNCTIONAL DESIGN/DEFINITION	8-2

CONTENTS (contd)

Section	Title	Page
	D DEVELOPMENT . . .	8-2
	1 Mission-Dependent Hardware	8-3
	2 Mission-Dependent Software	8-3
	3 Mission-Dependent Operations Plans/Procedures	8-4
	E TEST PLANNING/TESTING .	8-4
	F SCHEDULE AND COST ESTIMATES .	8-5
IX	CONCLUSIONS .	9-1
	A TECHNICAL FEASIBILITY . .	9-1
	B IMPLEMENTATION	9-1
	C SUPPORTING RESEARCH AND TECHNOLOGY	9-1
X	PHASE B STUDY PLAN . .	10-1
	A OBJECTIVES	10-1
	B STUDY APPROACH .	10-2
	1 Establishment of Constraints and Interfaces for LRV Operations Design/Definition . .	10-2
	2 Development of the LRV Operations Design/Definition	10-4
	3 Implementation .	10-5
	C WORK PLAN . .	10-6
APPENDICES		
	A REFERENCES	A-1
	B NOMENCLATURE .	B-1
	C SCIENCE EXPERIMENTS	C-1
	D INSTRUMENTS	D-1
	E SCIENCE OPERATIONS . .	E-1
	F TEST CLASSIFICATIONS . . .	F-1

ILLUSTRATIONS

Figure	Title	Page
1-1.	Relation of the Science Ground Data System to the Mission Operations Complex	1-2
3-1	Science Subset of LRV Mission Operations Complex	3-2
3-2	Elements of the Science Ground Data System	3-4
3-3	Data Sources	3-5
3-4	Mission-Independent Data Flow Diagram for the Science Ground Data System	3-9
4-1	Science Data Stream: Generalized Data Flow Diagram for Data from a Single Instrument	4-7
4-2	Science Data Stream: Simplified Data Flow Diagram for Data from a Single Instrument	4-8
4-3	Science Data Stream. Data Flow Diagram for Combined Instruments	4-9
4-4	Imaging Data Flow Diagram	4-19
4-5	Payload Engineering Data Flow Diagram	4-27
5-1	Outbound Command Data Flow Diagram	5-3
5-2	Inbound Command Data Flow Diagram	5-8
6-1	Plan A for the Science Operations Organization	6-5
6-2	Plan B for the Science Operations Organization	6-7
8-1	Implementation Schedule for the Science Ground Data System and Science Operations Organization	8-7
8-2	Cost Estimate and Manpower Schedule for the Science Ground Data System and Science Operations Organization	8-8

TABLE

Table	Title	Page
D-1	Use of Instruments to Support Experiments	D-11

SECTION I
INTRODUCTION

A SUMMARY

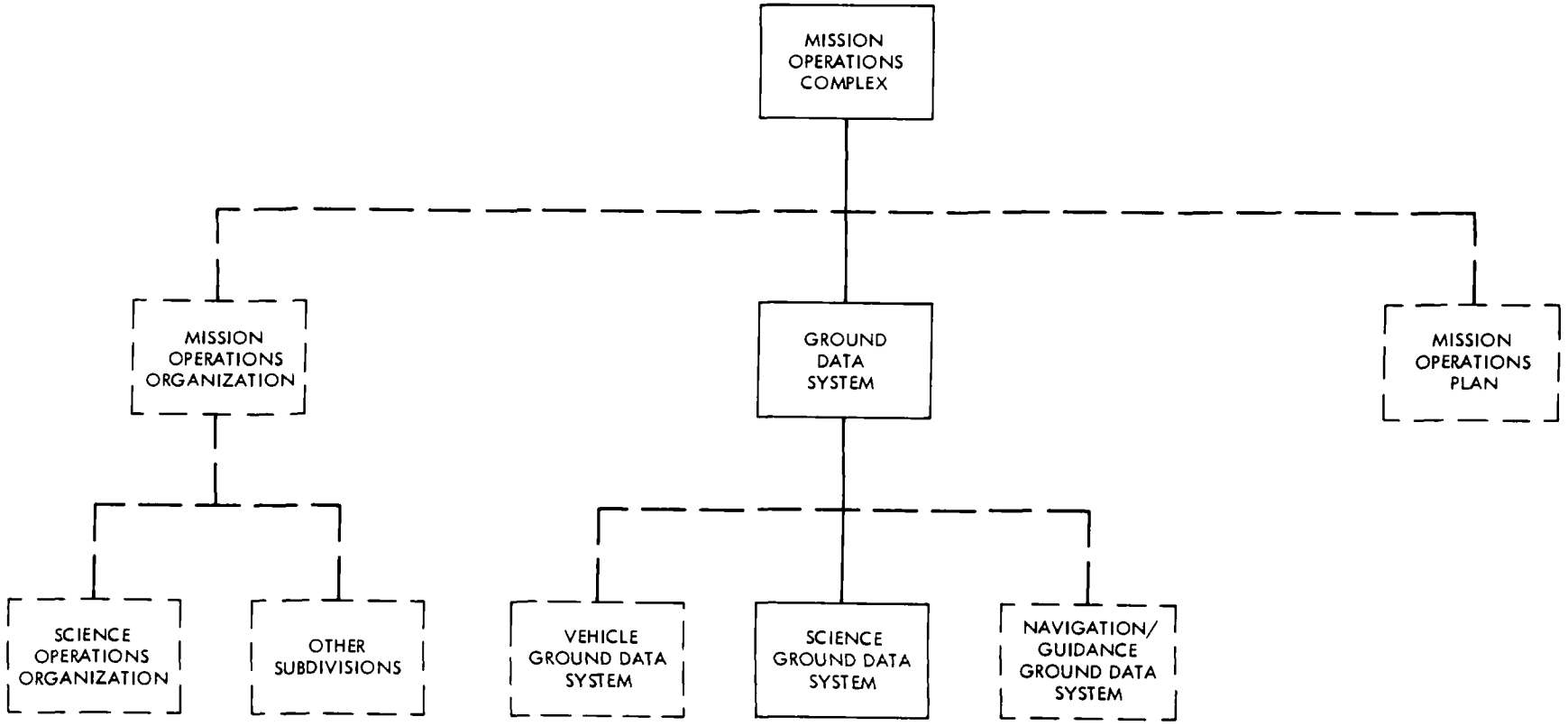
This report describes early mission operations planning for the ground support of science operations by a lunar surface-roving vehicle The vehicle's mission is geological and geophysical reconnaissance plus terminal rendezvous with an astronaut Both the vehicle and its science payload will be controlled from Earth The report presents a preliminary functional design of the data processing and organizational elements of the ground system required to support science operations The experiments and instruments involved in meeting the science objectives of the mission are enumerated and their requirements on ground operations are identified

The gross structure of the Mission Operations Complex* to provide all ground support is shown in Figure 1-1 Its logical functions are divided into three groups. hardware and software functions (Ground Data System), human functions (Mission Operations Organization), and plan functions (Mission Operations Plan) Each of these has components arising not only from science operations (described herein) but also from the need to navigate and guide the vehicle (described in Reference 1*) and to maintain the vehicle in operational readiness condition (description in future studies) Mission-independent ground support is planned to be utilized wherever available

The Science Ground Data System is comprised of subsystems for the handling and processing of telemetry data and command data (described herein) and tracking data (to be described in Phase B) Two alternate designs, based upon different philosophies of command, are presented for the Science Operations Organization and will be resolved in Phase B The report describes early plans for implementation of the Science Ground Data System and Science Operations Organization, identifies problem areas, and presents an outline for Phase B definition studies

---

*For references see Appendix A, for definition of terms see Appendix B



760-39

Figure 1-1 Relation of the Science Ground Data System to the Mission Operations Complex

No significant factors precluding feasibility of the mission from the viewpoint of mission operations were encountered. The design, development, and testing of the Science Ground Data System and Science Operations Organization are estimated to require four years and 3.7 million dollars. Supporting Research and Technology is needed in the general ground support areas of sampling, TV assessment, opportunity exploitation, topographic mapping, payload engineering, and elevation determination.

B OBJECTIVES

The objectives of this study were:

(1) To provide, as a forerunner to subsequent development of the total Ground Data System (GDS) in Phase B, a preliminary description of the functional characteristics which will be required in the Science Ground Data System (SGDS) and Science Operations Organization (SOO) for science operations planned to be conducted during remotely controlled lunar traverses, (References 2, 3, and 4).

(2) To provide information concerning the impact of mission operations upon general project and preliminary mission planning, including required Supporting Research and Technology, plans for implementation, and projections of cost.

(3) To identify problems needing solution.

C SCOPE

This report concerns preliminary functional design studies of the SGDS and SOO for a remotely controlled Lunar Roving Vehicle (LRV). The report identifies mission-dependent functional capabilities within the Space Flight Operations Facility (SFOF) which are required for on-line support of Telemetry and Command Data Subsystem operations associated with science experiments anticipated for the remotely controlled LRV. Navigation and guidance considerations for this mission, studied independently of and not necessarily correlated

with this study, are reported in Reference 1 Mission-independent data function capabilities equivalent to those of the Deep Space Network (DSN) Mark III (Reference 5) are assumed herein to be available for use

The report stresses capabilities to be provided, rather than the sequential or repetitive use of such capabilities to achieve desired ends. It specifically excludes description of the vehicle and of the science experiment rationale (References 6, 7, and 8). These matters are accepted herein as baseline constraints.

D. STUDY APPROACH.

The operations study, of which this is the first report, covers two NASA Project Planning Phases (A and B) (Reference 9). In Phase A, the mission operations associated with science experiments have been studied separately from those associated with the Navigation and Guidance System and are reported here separately. In Phase B, these two aspects will be studied and reported as one system, as described in Section X of this report.

The sequence of design activities was as follows

(1) Collection of experiment definitions
(2) Identification of probable instruments
(3) Establishment of science requirements upon mission operations
(4) Generalized description of experiment operations
(5) Preliminary design of SGDS to meet requirements (3) and identification of problem areas for later study
(6) Preliminary design of SOO to meet requirements (3)
(7) Preliminary implementation plan and estimate of cost

The experiments presumed likely for the LRV mission (Appendix C) and the corresponding instruments taken as a baseline payload for this study (Appendix D) were set by Dr. Roy G. Brereton of the Advanced Lunar Studies (ALS) Team at JPL and later reviewed by Dr. Leonard Jaffe of the ALS Team.

The approach taken in functional design of the Science Ground Data System was to

(1) Identify the science data streams and their contents.
(2) Interpret the science requirements for data functions upon the data streams.
(3) Identify the mission-independent data function capabilities which are currently available within the DSN.
(4) Add, for each data subsystem within the Science Ground Data System, the necessary mission-dependent data functions and depict their relationships in a functional flow diagram.
(5) Check the results in (4) for conformity with the science requirements, for feasibility, and for functional compatibility with interfacing elements of the SGDS.

The approach taken in functional design of the Mission Operations Organization for support of LRV science operations was to

(1) Identify the basic or fundamental human functions which must be performed in order to meet the goals of the mission.
(2) Allocate the functions in (1) among operational groups. The criteria for such allocation were minimization of operational interfaces and enhancement of operational efficiency.

E. ASSUMPTIONS.

(1) Vehicle capability For the present study it is assumed that the vehicle has, in the remotely controlled mode (regardless of whether or not it is a dual-mode vehicle), capability equivalent to that of the LRV described in Reference 4.
(2) Navigation and guidance of the LRV: It is assumed that the SGDS need not include functions for navigation and guidance of the LRV

(3) Navigation data It is assumed that the Navigation and Guidance Data System will furnish to the SGDS the selenographic position and heading of the LRV at each Science Operations Site.

(4) Integration of experiments It is assumed that the experiments to be conducted in LRV are interrelated and that achievement of mission goals will require continuous real-time interchange of conclusions derived from separate experiments

(5) Mission-dependent elements in the DSIF and/or GCF It is assumed that there will be no mission-dependent equipment or personnel in the Deep Space Instrumentation Facility (DSIF) or in the Ground Communications Facility (GCF).

(6) Earth-to-Moon distance ranging Science requirements for determination of the physical libration of the Moon and the distance of the LRV from the Moon's mass centroid are assumed to be met by the Science Tracking System and are not considered in this study.

SECTION II
LRV MISSION DESCRIPTION

A. MISSION OBJECTIVES

On the basis of theory and Earth-based observation, together with results of U. S and Soviet lunar flight missions, credible objectives for continuing lunar exploration have been described in References 6, 7, and 8. Fundamental to these is the concept of mobile investigators (men, machines, or a combination) exploring outward from lunar landing sites and sampling lunar surface properties enroute. The objectives of these surface traverses are (1) to permit the extension of isolated observations and the generalizing of discrete findings into a unified understanding of the lunar surface, and (2) to provide base measurements (ground truth) for overhead surveys of broad areas The overhead surveys are, in turn, essential in the planning and support of the traverses, as well as for the development of understanding at regional and planetary scales

For geology and geochemistry, a long traverse is important because it affords an opportunity to make observations and take samples, not only in detail at a particular feature, but also across major regional units. For geophysics, a long traverse offers the prospect of profiling, gravimetry, geodesy, and structural discrimination across major geological provinces. For astronomy, a long traverse offers an opportunity for comparing and evaluating widely separated observatory sites and for determining the physical libration of the Moon

In each of these disciplines and in their ensemble, the long traverse (assuming proper coordination with overhead surveys and local explorations in depth at a few sites) presents an opportunity for making those critical measurements that permit rational decisions as to future exploration and exploitation of the Moon

B. MISSION CONSTRAINTS

Because of technical constraints on manned lunar operations, traverses extending more than a few tens of kilometers from a landing site will, at least in the near future, have to be automated or controlled remotely (semi-automatic) The scientific experiments carried will have to be kept rather simple and, in particular, a full-scale analysis of lunar materials in situ, including isotopic analysis and age dating, is out of the question However, geochemical analysis is important to the mission Therefore, the collection of lunar samples for eventual return to Earth is a priority mission goal.

Because of vehicle and operational limitations the LRV will be constrained to operate on the Moon's Earthward face and with minor exceptions, only during the lunar day

C THE REMOTELY CONTROLLED SCIENCE MISSION

1 Science Goals

Specific science goals for the remotely controlled mission are:

(a) To acquire, for return to Earth, samples of lunar soil and rock material and to deliver them to a specified rendezvous site
(b) To provide geological reconnaissance of the lunar surface
(c) To conduct lunar geophysical investigations
(d) To enable measurement of lunar libration
(e) To explore and evaluate sites of scientific opportunity for future missions

2 Description of Science Mission

The LRV is a self-powered, wheeled, surface vehicle equipped with on-board telecommunications, scientific, and navigation and guidance equipment The vehicle will execute a planned series of scientific activities under control from Earth This plan will include time allowances to investigate unexpected

discoveries of scientific interest. To do so, it will move from one planned site to another, stopping at each site in order to permit conduct of its prime scientific functions

Scientists on Earth, viewing the scene about the LRV through television, will classify the terrain according to its geological nature and will specify minor alterations in course to reach the most desirable locations for observing. As the vehicle advances, the contour map of the visible zone will be prepared automatically using data from vehicle sensors

Samples of the lunar surface material, both soil and rock, will be picked up by the LRV and photographed at very close range stereoscopically Samples of particular interest will be analyzed further to determine their mineral content and chemical composition A selected set of samples will be retained on board for ultimate return to Earth

Magnetic field measurements will be taken continuously and may require intermittent deployment of the instrument from the vehicle to eliminate vehicle-induced effects Similarly, gravity measurements involve placement of the Gravimeter on the terrain surface and subsequent stowage Interpretation of the gravity findings requires determination of the vehicle's elevation by a slope-integration procedure, by ranging from Earth, or by collaboration with lunar orbiting vehicles Active seismic investigations, involving the emplacement and detonation of explosive charges, are assumed to be undertaken at selected sites Soil mechanics properties will be studied through accelerational instruments applied to the ground surface, through visual observation of the depression induced by controlled static pressure, and by scanning of the tracks left by the LRV Remote geophysical monitors (RGMs) will be deployed at pre-assigned locations by installing them on the ground and leaving them Each RGM can function automatically and transmit data directly to Earth.

Mobile science operations will be conducted only while the LRV is in sunlight, which is a cyclically recurring, two-week-long period interspersed by two weeks of darkness During periods of sunlight at the LRV, telecommunications with Earth will be maintained continuously The LRV may be held at a

fixed site for protracted periods of daylight in order to view the change in shadow patterns, or for other scientific purposes

Features of scientific interest which are discovered enroute will be investigated to a degree commensurate with their estimated scientific worth Sites for future lunar activities will be explored to the degree possible

At the end of a year's exploration and after traversing more than a thousand kilometers, the vehicle will be directed to a rendezvous site where it will be met by an astronaut who will remove its collected geological samples and return them to Earth

SECTION III
SCIENCE GROUND DATA SYSTEM

This section of the report describes (1) the role and structure of the Science Ground Data System as a functional element of the total operational support of the mission, and (2) the functions required for execution of individual experiments, as preliminary information needed for the functional design of the Science Telemetry and Science Command Data Subsystems. The fundamental design approach taken in this study follows the established pattern developed in prior JPL flight projects. Mission-dependent data functions are treated in Sections IV and V.

A. SGDS FUNCTION WITHIN THE MISSION OPERATIONS COMPLEX.

1. Relation of SGDS to Mission Operations Complex

The Mission Operations Complex (MOC) for the remotely controlled LRV Mission is the aggregate of all elements on Earth required for operations of the LRV. As shown in Figure 3-1, it comprises three major parts the Ground Data System (hardware and software), to which this section of the report pertains, the Mission Operations Organization (personnel and operations procedures), which is treated in Section VI of the report, and the Mission Operations Plan (sequences of events, schedules, etc), which will be treated in the Phase B report.

The Ground Data System, in turn, comprises three elements: the Science Ground Data System, the Navigation and Guidance Ground Data System, and the Vehicle Ground Data System. The Science Ground Data System is the subject of this report. The Navigation and Guidance Ground Data System is treated in Reference 1. The Vehicle Ground Data System is planned to be treated in Phase B (see Section X).

The function of the Ground Data System is to provide an adequate medium by which the personnel of the Mission Operations Organization can execute the

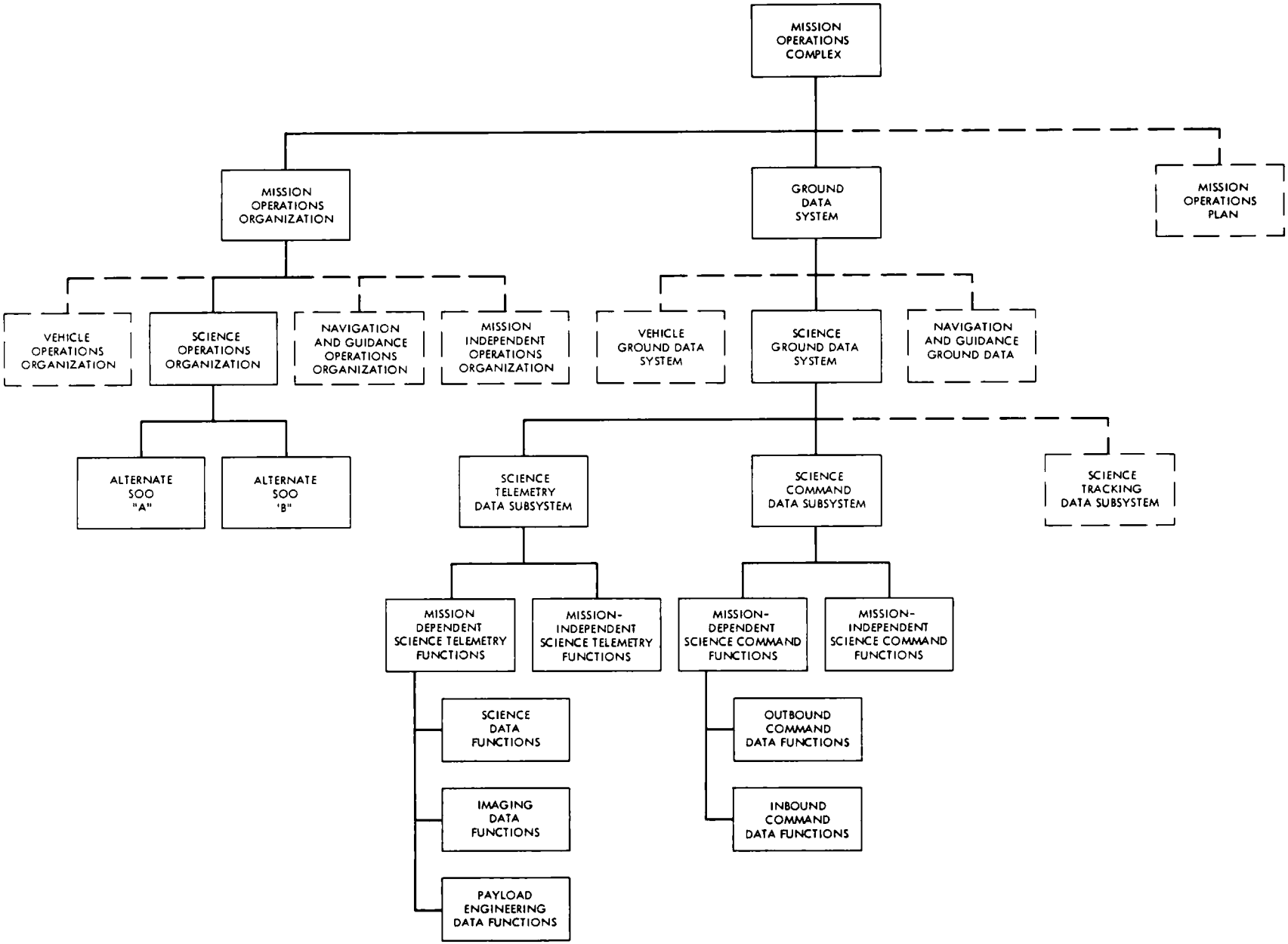


Figure 3-1 Science Subset of LRV Mission Operations Complex

Mission Operations Plan. The function of the Science Ground Data System is that subset of the functions of the GDS which concern science operations That is, the function of SGDS is to provide an adequate medium by which the personnel of the Science Operations Organization (see Section VI) can execute the science portion of the Mission Operations Plan

2. Data Subsystems of SGDS

As shown in Figure 3-2 the Science Ground Data System comprises two major subsystems which are treated in this report (Science Telemetry Data Subsystem and Science Command Data Subsystem), plus the Science Tracking Data Subsystem, which will be studied in Phase B, plus other subsystems such as Monitoring, Operations Control, and Simulation, which are assumed to be mission-independent and for that reason have been omitted in this preliminary study.

The Science Telemetry Data Subsystem includes all payload data which flow from the Moon to Earth and comprises three subdivisions: science data functions, dealing with science instrument output data, imaging data functions, dealing with arrayed data, and payload engineering data functions, dealing with instrument status. The Science Command Data Subsystem includes all functions related to command and control of the science instruments and comprises the outbound command data functions (generation and transmission to the LRV) and inbound command data functions (verification and confirmation of issued commands) Functional design of the Science Telemetry Data Subsystem is described in Section IV of this report and functional design of the Science Command Data Subsystem in Section V.

B. DATA SOURCES.

The data upon which the Science Ground Data System operates arise from:

(1) Outputs by the science instruments carried as payload aboard the LRV.

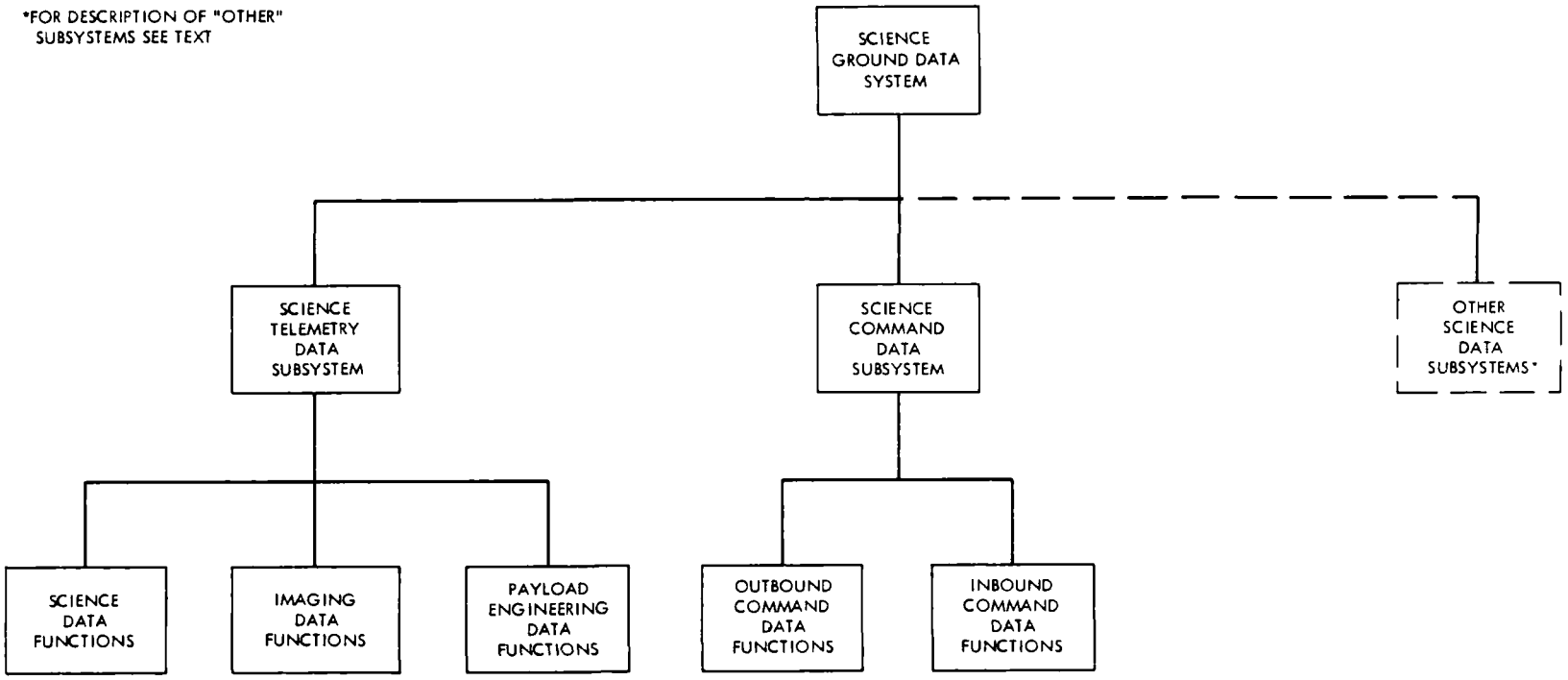


Figure 3-2 Elements of the Science Ground Data System

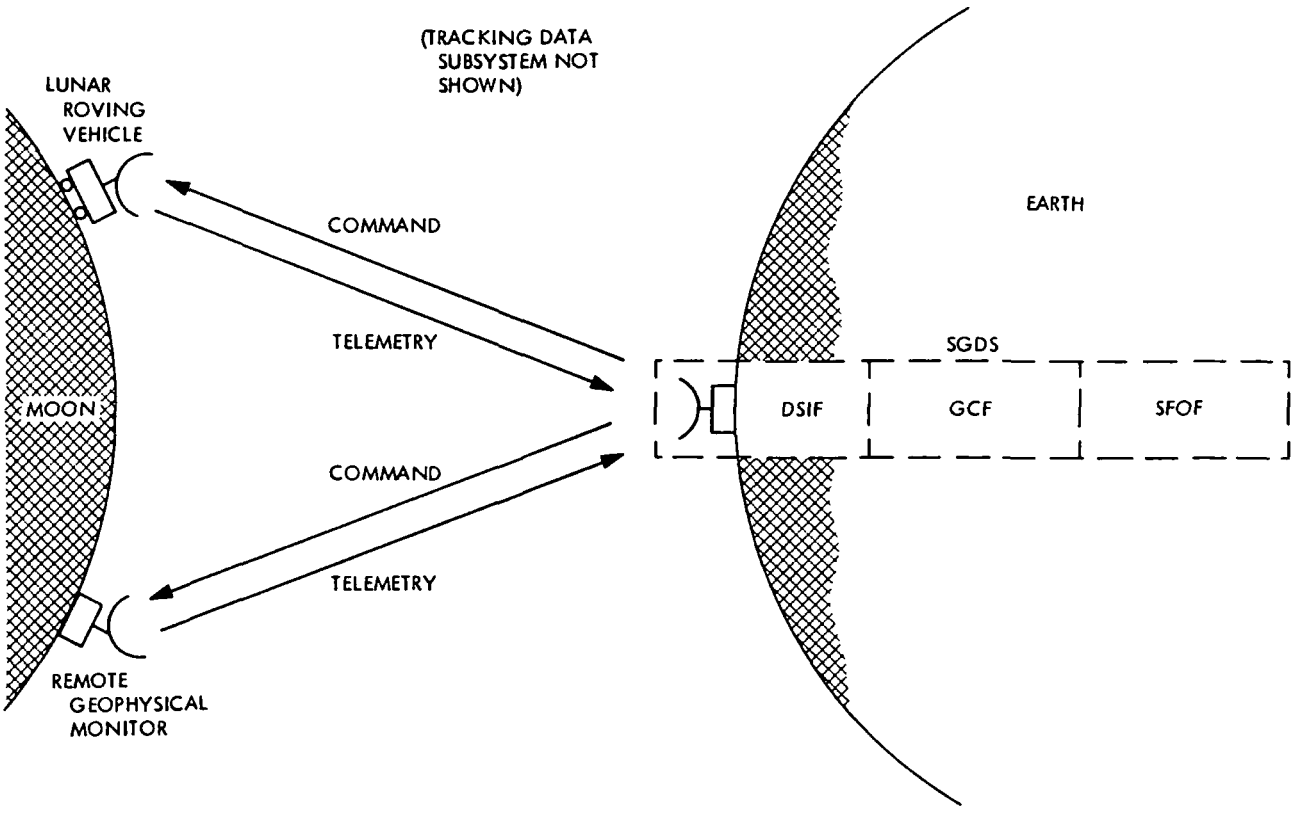


Figure 3-3 Data Sources

(2) Outputs from vehicle-borne sensors determining the condition of the instruments

(3) Outputs by science instruments in stationary science instrument installations on the lunar surface (RGMs)

(4) Inputs by operations personnel.

(5) Simulation Data System inputs to SGDS (not treated here).

The flow of these data into the SGDS is shown diagrammatically in Figure 3-3. For simplicity, only one RGM has been represented in the illustration, but more than one will generate data in the assumed mission

C. DATA FACILITIES.

In the conduct of mission operations it is necessary to provide (1) telecommunication with the space vehicle, (2) reduction of received data to interpretable forms and issuance of commands for control of the spacecraft as

may be required, and (3) communication between the locations at which these functions are performed In the Deep Space Network these several functions are performed, respectively, by the Deep Space Instrumentation Facility (telecommunications), Space Flight Operations Facility (data processing and command/control), and Ground Communications Facility (intercommunications between SFOF and DSIF) As stated in Section I, the present report is concerned with mission-dependent data processes in the SFOF only.

D MISSION-INDEPENDENT DATA-FUNCTION CAPABILITIES

The Deep Space Network has been planned (Reference 5) to provide those data-function capabilities which are needed in common by the space projects currently foreseen. Thus, the DSN will provide a substantial portion of the total data function capabilities required by the LRV Mission Those capabilities which are needed by the LRV but are not furnished by the DSN must be provided by the Project. Generic data-function capabilities provided by the DSN include data handling, processing, display, selection, distribution, storage, and retrieval as defined in Appendix B

The standard treatment of data within the mission-independent portion of the SGDS is shown diagrammatically in Figure 3-4. Data from all sources enter the SFOF in four separate data streams. Only one data stream emerges from the mission-dependent into the mission-independent portion of the SFOF The treatment of the data within the mission-dependent portion of the SGDS is described in Sections IV and V.

E EXPERIMENTS

The design of the Science Ground Data System is intimately related to the operations which are required for the science experiments to be performed The baseline set of experiments to be conducted in the LRV Mission is identified below. Because no single-source document describing the plan for execution of these experiments was available to guide development of the design of the SGDS, the descriptions were compiled, and are presented in Appendices C, D,

and E, to provide such a reference Each description includes a summary of the scientific equipment on the LRV which is utilized in support of the experiment to be executed on the Moon, the data processing support required on Earth, the displays which are required on Earth for human monitoring and command/control of science operations, and the command decisions which must be reached

1. Baseline Experiments

Eleven distinct experiments are assumed to be nominally standard for the LRV Mission for the purposes of this report. These are:

(a) Visual terrain assessment
(b) Visual examination of samples.
(c) Samples for return to Earth.
(d) Mineral phase analysis
(e) Chemical element analysis
(f) Gravimetry.
(g) Magnetometry
(h) Soil mechanics
(i) Active seismometry.
(j) Earth-distance ranging.
(k) Remote geophysical monitors (cf. paragraph II.C 2)

The objectives of these experiments are outlined functionally in Appendix C The list includes all experiments cited by the U S Geological Survey for LRV (Reference 8)

2 Baseline Instruments

The instruments assumed herein for the LRV Mission are:

(a) Panoramic TV Camera (facsimile).
(b) Foreground TV Camera (image dissector)
(c) Sample TV Camera (image dissector).
(d) Soil Sampler (scoop bucket).

(e) Rock Sampler (chipper/tongs)
(f) Soil Auger
(g) Rock Core Drill
(h) Sample Storage
(i) X-Ray Diffractometer
(j) X-Ray Spectrometer
(k) Vector Magnetometer
(l) Gravimeter
(m) Retroreflector
(n) Seismic Charge Emplacer (and charges)
(o) Seismic Charge Detonator
(p) Seismic Sensor
(q) Remote Geophysical Monitors (RGMs)
(r) Inclinometer
(s) Gyroscope
(t) Laser Radar
(u) Penetrometer
(v) Laser Range Finder

The functions of these instruments are described in Appendix D. Instruments which have been proposed by others but are not included in this report are also listed in Appendix D. It is recognized that not all of these instruments may be carried on any one mission. However, the SGDS must be able to handle various subsets from the assumed list, so numerous interactions have to be considered A detailed description of the baseline experiment set, along with implied requirements on the Science Ground Data System functional design and Science Operations Organization definition are presented in Appendix E

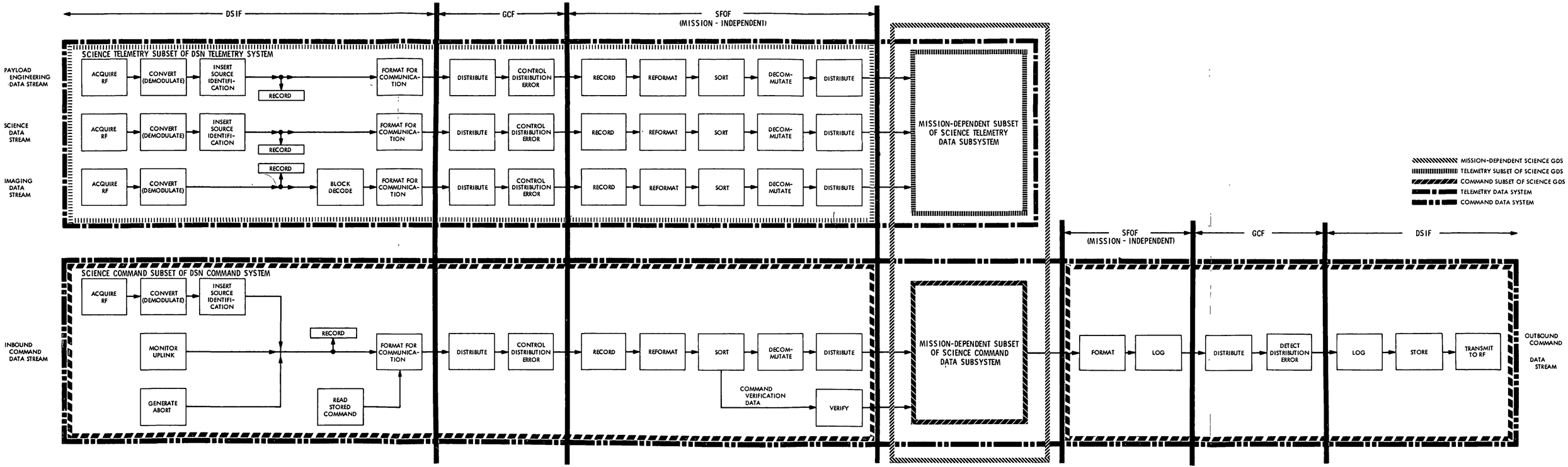


Figure 3-4. Mission-Independent Data Flow Diagram for the Science Ground Data System

SECTION IV
SCIENCE TELEMETRY DATA SUBSYSTEM

This section describes the mission-dependent functions which are performed in the Science Telemetry Data Subsystem of the SGDS (see Figure 3-2) The three separate data streams which are inherent within telemetry are first identified Data functions common to all data streams are presented Next, the mission-dependent data functions peculiar to each separate data stream and the flow of data in that stream are described The data-flow diagrams in this section constitute, collectively, an expansion of that portion of Figure 3-4 which is labeled "Mission-Dependent Subset of Telemetry Data Subsystem " In all cases, the data-flow diagrams represent unidirectional flow of primary data from left (origin) to right (destination), with internal data interfaces being shown at top and bottom. The origin here of all data from the LRV is taken at the interface, within the SFOF, between mission-independent and mission-dependent data functions.

A. TELEMETRY DATA STREAMS.

The concept of "data streams" in connection with the functional design of data systems refers to the flow of data through the network of data functions which comprise the data system. The total of all flow through all functions can conveniently be subdivided into essentially independent subsets, according to the source and type of the data. These subsets of the total data flow are termed here "data streams." It is important to note that this concept of data stream is related to the identity of the data flowing and is not necessarily related to the physical equipment used. Two data streams, in the sense used here, may flow through the same physical equipment.

Three separate data streams occur in the Science Telemetry Data Subsystem. The first subdivision arises from the distinction between information concerning the time-varying condition of science instruments versus the primary information which such instruments emit as a measurement of their environment. The information concerning the condition of instruments is

termed herein "Payload Engineering Data" and the flow of such data through the Science Telemetry Data Subsystem is termed the "Payload Engineering Data Stream."

The second subdivision of Science Telemetry Data according to data source lies in the distinction between Imaging Data, which are two-dimensional information arrays, versus Science Data, the term assigned here to all science instrument primary outputs other than Imaging Data. (Note as a result, that the term Science Data, as used here, does not include all data within the Science Ground Data System.) The flow of Imaging Data is termed the "Imaging Data Stream" and the flow of Science Data is termed the "Science Data Stream."

B. DATA FUNCTIONS COMMON TO ALL DATA STREAMS.

Before describing the data functions which are peculiar to specific data streams, it is convenient to assemble those data functions which are performed upon all data streams within the Science Telemetry Data Subsystem. Definitions of the classes of data functions are presented in Appendix B.

1. Selection.

There are a number of sources of telemetry data streams entering the mission-dependent SFOF portion of the Science Telemetry Data Subsystem. The capability to select the data streams from one or the other of these sources should be provided. Selection capability is needed to enable operational (human) control over the following data functions

(a) Conversion of telemetry measurements into engineering or scientific units.
(b) Alarm limit detection and editing.
(c) Data processing, i.e., selection of engineering and science analysis functions.
(d) Display of functions and formats.
(e) Data retrieval from storage.

2. Data Handling.

Mission-dependent data handling functions required in the SFOF include the following

(a) Converting the engineering and science telemetry data to values in appropriate engineering and science units.

(b) Converting the video data to image data for display (real-time scan-converted image) and hard copy.

(c) Editing of a subset of engineering and science data channels for limit checks and detecting of data points which exceed the defined limits for display.

(d) Providing temporary engineering, science, and video data storage (and retrieval) in order to establish a centralized information source for all subsequent data processing.

(e) Upon request from mission operations personnel, locating selected data in temporary storage or in the Master Data Records (MDR). The data will be locatable by time, source identification, and data type.

(f) Accepting standards and limits for telemetry data and formatting appropriate standards and limits messages for transmission to areas or facilities.

(g) Compiling a Master Data Record. Telemetry MDRs should be produced in near-real time by the Science Telemetry Data Subsystem. General characteristics of the telemetry MDR are as follows

(1) Data is compatible with the computer (the MDR will normally be recorded on digital magnetic tape).

(2) Data is decommutated, placed in time sequence, and arranged or identified according to source and data type identification.

(3) Duplicate and extraneous data is removed (recalled data is accepted from the station and fitted into the MDR in proper sequence).

3. Data Distribution.

Within the SFOF, provision is needed for the distribution of telemetry data to all mission support areas. The data distributed will consist of all or portions of the following

(a) Selected words formatted for display. (It will be possible to select, for distribution to a single user, data from any of the different data streams.)
(b) Complete sequences of data (such as frames) with time tags and other status or labels.

The distribution of telemetry data will be specified, either by real-time inputs from the mission support areas, by prior specification in mission plans and sequence of events, or by direction from mission-dependent analysis software.

4. Data Display.

Data received by or processed by the Science Telemetry Data Subsystem are normally displayed in one or more of the following informational forms

(a) Status lights
(b) Digital readout (transient)
(c) Printed tabulation
(d) Video displays
(e) Hard copy plotters
(f) Hard copy photographs
(g) Film projections

5. Data Processing.

The telemetry data processing capability to be provided in the SFOF relates to the analysis of the engineering and science data and the derivation of

"new" information from the original data. The specific mission-dependent computer programs needed to do this processing are described in the treatment which follows.

C. DATA FUNCTIONS UPON THE SCIENCE DATA STREAM.

The flow of data within the mission-dependent portion of the Science Data Stream is shown in Figures 4-1, 4-2, and 4-3. These diagrams are related to Figure 3-4 and represent the Science Data portion of that element in Figure 3-4 which is labeled "Mission-Dependent Subset of Telemetry Data Subsystem." The data-flow diagram depicting the data functions for all instruments in combination is complex, and two introductory figures are presented to lead into it. Figure 4-1 shows the general relationship of the data functions for any single instrument. Figure 4-2 shows the simplified format employed in the comprehensive diagram for all instruments in combination. This simplified format is used on the main diagram, Figure 4-3, to reduce its complexity and improve its comprehensibility. After an initial discussion in the following paragraph of those data functions which are common to all science instruments, the data functions peculiar to each instrument are treated separately.

1. General Science Data Functions.

Six functions are applied in general to all incoming data, i.e., Conversion to Standard Units, Adjustment for Payload Engineering Corrections, Alarm Detection, Data Storage, Generation of Plot Data (to all data to be plotted graphically), and Spatial Analysis. For simplicity, each of these common functions has been shown by a single rectangle enclosing all the data flow lines. Alarm conditions in the data will be detected by comparing the magnitude of the data versus alarm limits. Such limits will be expressed as variable functions of time and will be resettable during execution of the mission. Detected alarms will be displayed tabularly and those of a type requiring automatic reaction will be transferred to the Command Data Subsystem. All Science Data will be recorded in retrievable form, with on-line access to that portion obtained from the current operations site and throughout the last preceding Earth day. Data

required to be displayed in graphic form will be transformed into the driving signals appropriate to the particular type of display used. Spatial* analysis, as used here, refers to the observed function's relationship to (selectively) either (1) the LRV position along the traverse or (2) the LRV position in mapping coordinates, and is performed for all instrument data except Seismometer data. The observed functions are plotted directly. The same functions are differentiated (differenced and normalized) to determine spatial gradients and these gradients are plotted.

2. Diffractometer Data Treatment.

Diffractometer data include the diffraction angle (which is stepped through a span of values), the measured response of the Diffractometer instrument, and the rate of stepping of the instrument through its span of diffraction angles. The sample identity specified by human input is associated with these data.

a. General Treatment. Scan rates are determined on Earth by differencing the times between successive data outputs by the instrument. The response of the Diffractometer instrument for any given sample is both tabulated as a function of the variable diffraction angle and plotted graphically to form a "diffractogram." The response data are then analyzed to determine the type and abundance of minerals present in the sample and the statistical uncertainties in such estimate, including the residuals in the observation which are not explained by the mineral assessment. These results are tabulated and the unexplainable residuals are plotted as functions of diffraction angle. Using the position of the LRV given by the Navigation and Guidance System, the plotting data for a profile of the abundance of each mineral are then updated and the updated profile displayed. The set of minerals present in the current sample is compared versus the sets of minerals present in previous samples and significant similarities identified and shown tabularly, as a function of position along the traverse. Trends with position along the traverse will be identified and significant discontinuities in the trends detected and shown tabularly as well as graphically.

*Temporal analysis analogous to this is not performed upon all instrument data.

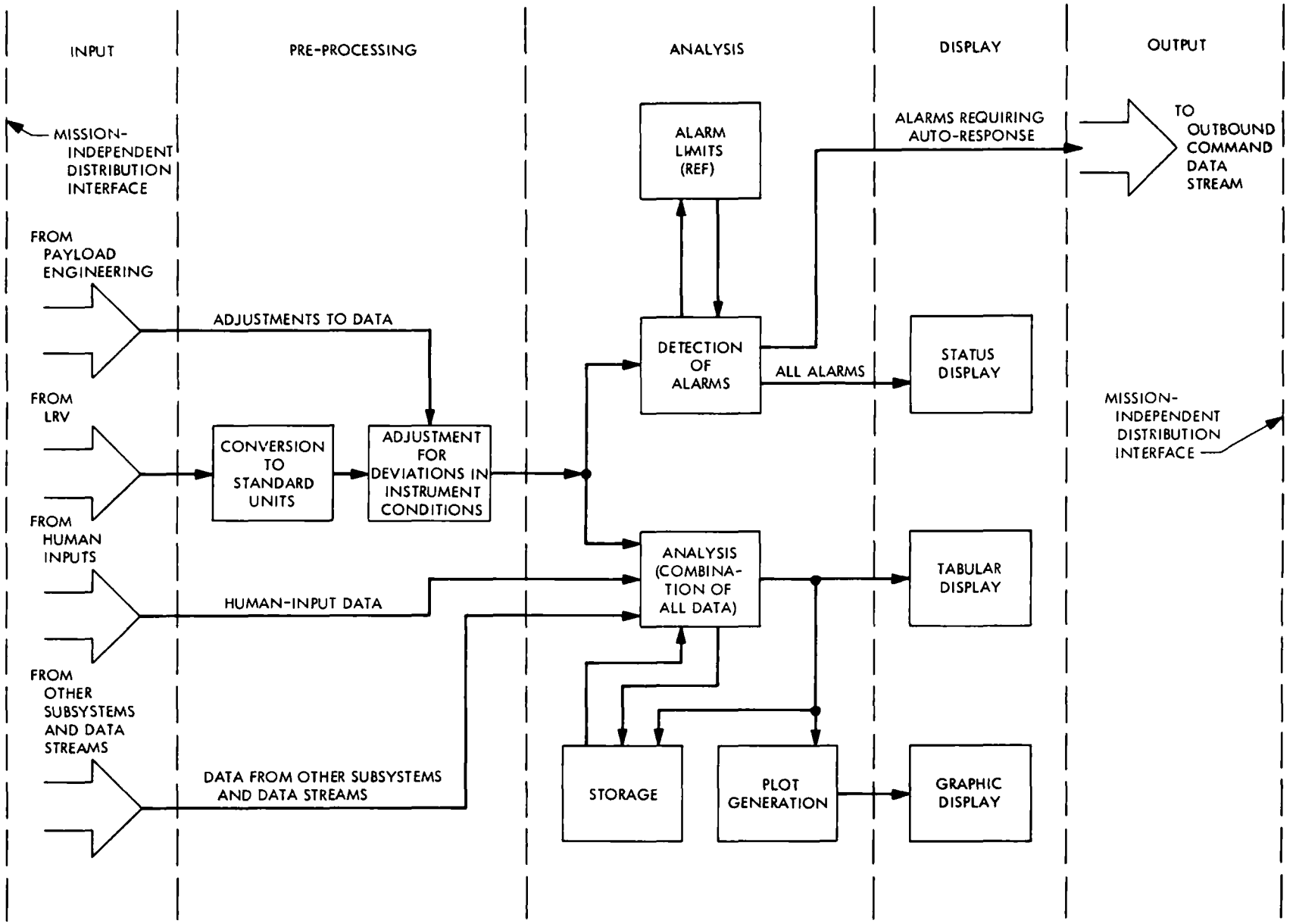


Figure 4-1. Science Data Stream Generalized Data Flow Diagram for Data from a Single Instrument

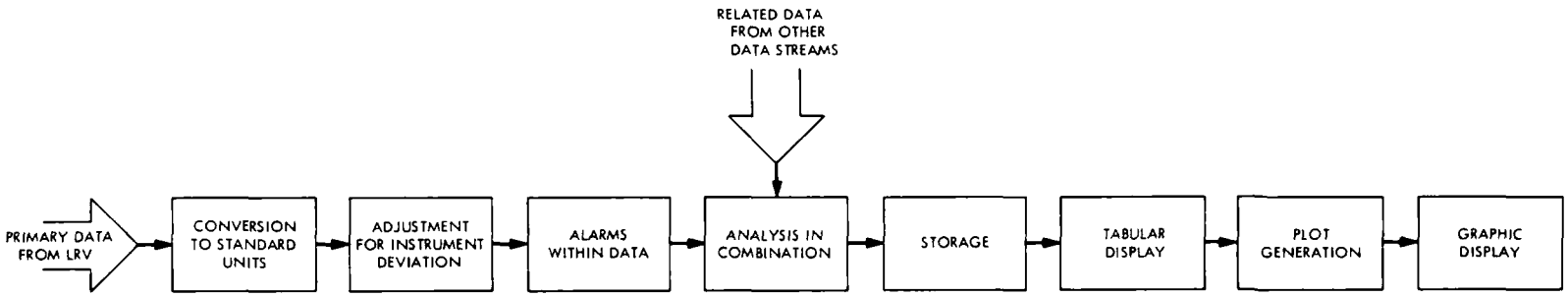


Figure 4-2. Science Data Stream Simplified Data Flow Diagram for Data from a Single Instrument

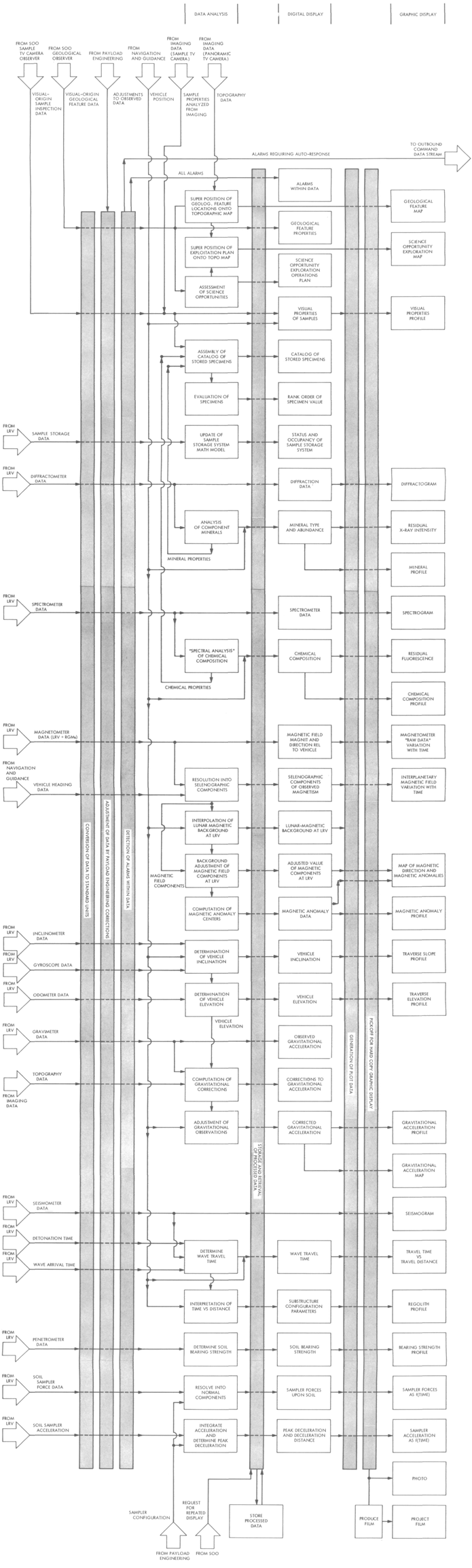


Figure 4-3. Science Data Stream: Data Flow Diagram for Combined Instruments

b. Computer Program. The "Analysis of Sample Constituents" Computer Program provides the automatic data reduction which is inherent in the interpretation of diffractograms and spectrograms to deduce the identity of minerals present in geological specimens, the relative abundance of such minerals, and the chemical composition of the specimen. The program provides display of diffractograms and spectrograms and of the residue remaining in such functions after deducting the function magnitude corresponding to the deduced values of minerals and elements. The program further determines the uncertainty in the deduced values of minerals present and chemical composition which is due to the length (duration) of the exposure to x-ray bombardment.

3. Spectrometer Data Treatment.

Spectrometer data include the wavelength of the incident energy which stimulates the specimen, the measured response of the Spectrometer instrument, and the rate of stepping of the instrument through its span of wavelengths. The sample identity specified by human inputs is associated with these data.

a. General Treatment. Scan rates are determined on Earth by differencing the times between successive data outputs by the instrument. The response of the Spectrometer instrument for any given sample is both tabulated as a function of the variable wavelength of the stimulus and plotted graphically to form a "spectrogram." The response data are then analyzed to determine the compositional fraction of chemical elements present in the sample and the statistical uncertainties in such estimate, including the residuals in the observations which are not explained by the analysis. These results are tabulated and the unexplainable residuals are plotted as functions of the wavelength of the stimulus. Using the position of the LRV given by the Navigation and Guidance System, the plotting data for a profile of the compositional fraction of each chemical element is then updated and the updated profile displayed. The pattern of chemical element proportions present in the current sample is compared versus the pattern of element proportions in previous samples and significant similarities identified and shown tabularly, as a function of position along the traverse. Trends with position along the traverse will be identified and significant discontinuities in the trends detected and shown tabularly as well as graphically.

b. Computer Program. The "Analysis of Sample Constituents" Computer Program described in paragraph C. 2. b above is also used for the treatment of Spectrometer data.

4. Magnetometer Data Treatment.

Magnetometer data are received from the LRV and each RGM. For each instrument, the data include the magnitude of the principal components of the magnetic field, the time at which the readings were taken, and the identity of the instrument.

a. General Treatment. For each instrument, the reading from each component sensor is plotted as a continuous function of time. Significant discontinuities in any individual sensor are detected, flagged on the plot, and tabulated. Using the known orientation of each Magnetometer (for the LRV this is given by the Navigation and Guidance System plus the Inclinometer and Gyroscope), the magnetic field components parallel to the reference coordinate system are found for each Magnetometer by resolution. The corresponding value of the interplanetary magnetic field at the LRV is then computed from knowledge of the LRV position, the magnetic field measurements at each RGM, and a theoretical model interrelating these factors. This interplanetary magnetic field at the LRV is plotted as a function of time. The corresponding initial time value of the interplanetary magnetic field strength and direction, at the present site of the LRV but at the mission-starting time, is computed by the same process. The initial value is deducted from the present value to establish the temporal change which has occurred in the magnetic field at the site currently occupied by the LRV. The selenographic components of the magnetic field observed by the LRV are then adjusted by this temporal change to show spatial variations in the lunar magnetic field. The local spatial variation data are added to the magnetic map plot file and the updated magnetic map is displayed. The magnetic map data (free of temporal variations) are analyzed to detect three-dimensional curvature and gradients in the field and to deduce centers of attraction and their magnitude (magnetic anomalies). These anomalies are added to the magnetic map data (and displayed) and their position shown on an elevation-profile through the traverse.

b. Computer Program. The "Magnetic Sources Location" Computer Program determines the selenographic components of the observed magnetic field at the LRV and at the RGMs, the interpolated temporal variation in the magnetic field at the LRV and at the RGM, the spatial variation in the vector magnetic field along the traverse, and the effective centers of spatial anomalies. The program plots the temporal variation of magnetism as a function of time, the spatial variation as a profile along the traverse, and the location of anomalies on such profile. These plots are kept updated continuously as open-ended plots by shifting forward in time.

5. Gravimeter Data Treatment.

The total data involved in gravimetry reduction include (1) the output from the Gravimeter plus (2) the observational data from the Inclinometer, Odometer, and Gyroscope and (3) reduced values of LRV position from the Navigation and Guidance System and the topographic map data from the Imaging Data Subsystem.

a. General Treatment. Measured values of the acceleration of gravity at the LRV are tabulated and their average for each position of the instrument computed. Two corrections to the observations are then computed and tabulated, one being related to the radial distance of the instrument from the lunar mass centroid (Free Air Correction) and the other to local irregularities in the distribution of lunar mass around the instrument site (Bouguer Correction). Changes in altitude as the LRV advances along the traverse (the basis of the Free Air Correction) are determined as changes in gravitational elevation and are computed by integrating the product of lunar surface slope times the distance traveled from the last measured altitude point. Pitch of the vehicle relative to the local vertical, which is approximately equivalent to the slope of the terrain surface, is measured by the Inclinometer when the LRV is stationary and by the Gyroscope while the LRV is in motion. The Gyroscope will be reset to the Inclinometer when the LRV stops. Both vehicle pitch and vehicle elevation will be tabulated at prescribed intervals along the traverse, including all stopping points, and will be plotted as continuous profile-functions of position in the traverse.

The correction to gravity observations due to local irregularities in mass distribution (Bouguer Correction) is computed, using the topographic data furnished by the Imaging Data Subsystem and LRV position furnished by the Navigation and Guidance System. The adjusted value of acceleration of gravity formed by applying the foregoing two corrections is then tabulated, the plot-display data files are updated, and acceleration of gravity is displayed as a profile-function of position in traverse and (where applicable) as a map function.

b. Computer Program. The "Gravimetry" Computer Program performs the computations outlined in a. above, averaging the gravity observations, determining ground slope and change in elevation, calculating corrections to the observations, and finally, determining the corrected value of the local acceleration of gravity.

6. Seismometer Data Treatment.

The total data involved in seismometry reduction include time of detonation of charges, response of seismic sensor, and position of charges and sensor, as furnished by the Navigation and Guidance System.

a. General Treatment. The position of the LRV as the charges are being emplaced and the seismic sensor is deployed is tabulated, stored, and plotted as a map function superimposed upon the topographic map. For each shot, the time of detonation and the seismic sensor response are plotted as functions of time, the time of arrival of the wave front at the sensor is detected and differenced from detonation time to establish the travel time and these data tabulated. Travel times for all the charges at any one deployment of the sensor are plotted as a function of distance from shot-hole to sensor, discontinuities in the plot indicating in a rough way discontinuities in the subsurface structure. The interpretation of the seismic data into a detailed mathematical model of the subsurface structure will be performed by a computer program, acting upon the geometric configuration data regarding the shot-holes and the wave-travel times. The principal parameters in these data will be tabulated, and selected vertical profiles (one being through traverse) will be plotted, including surface elevation data from the laser radar.

b. Computer Program. The "Seismic Analysis" Computer Program analyzes the vehicle's position data during charge emplacement to determine the vector separation between individual shot-holes and the seismic sensor, analyzes the seismic sensor response to establish the time of arrival of the head of the seismic wave and hence the time of travel of the wave, and then correlates these two factors over the set of seismic charges at any one seismic experiment site, to determine the best analytical model of the subsurface structure.

7. Sample Handling and Storage Data Treatment.

The Sample Handling and Storage data consist of articulation data for Sample Handling and Storage manipulators, engagement data showing when sample cup holders enter or leave identifiable stations, and Sample Handling data keyed by human observers.

a. General Treatment. The identity number of each new sample (as established by keyed information) is checked for the possibility of duplicate assignments by automatic updating of sample acquisition serial number on the basis of change in LRV position. Sample identity number is inserted into all mechanical data and shown on displays. All data received are recorded and tabulated.

The model of the Sample Storage System and its occupancy is updated by all mechanical data indicating changes in that system and the changes tabulated. Keyed data concerning observed changes in the Sample Storage System are compared versus mechanical data and any discrepancies displayed. Occupancy-register of samples in the Sample Storage System is tabulated upon demand.

b. Computer Programs. The "Sample Storage Filing Data" Computer Program maintains a record of the identity, geological properties, location, and status of all lunar material samples submitted to the Sample Storage and Transport System. Such samples include (1) particulate soil samples retained in cups stored in pigeon-hole compartments (rows and tiers), or in transit through the system, (2) rock core samples, and (3) irregular rock

specimens in plastic bags. The samples can be in transit through the Storage System, stored in storage compartments, retained in bulk (open) storage, or held at the x-ray analysis station or at the sample photo-imaging station. The statistical properties of specimens include their identity, source location, mineral type and abundance, chemical composition, retention status, need for more extensive analysis, etc. The program includes determination of next available storage locations, need for further analysis, retrieval of specimens, preparation of specimens for processing, physical identification of specimens, etc. This program interfaces with and services the "Prior Sample Search and Comparison" Computer Program.

The "Prior-Sample Search and Comparison" Computer Program compares the circumstances of prior samples to the circumstances of a new sample which is a candidate for storage and return to Earth. The program evaluates the scientific worth of all stored specimens and of the candidate specimen, according to a pre-determined sample-return-value criterion (which can be altered in real time). If there is no available storage accommodation for the candidate specimen, the program selects for study the least valuable prior specimen, makes a value comparison with the candidate specimen and displays a definite recommendation as to whether to leave or replace the least valuable prior specimen. The sample-return-value criteria consider the "representativeness" of the specimen, its uniqueness, replication, relationship to geological contact definition, etc.

8. Sample Inspection Data Treatment.

The total data for Sample Inspection include Sample Inspection observational data keyed by human observers, sample identity number from the Sample Handling and Storage System, and sample optical data from the Imaging Data Subsystem.

a. General Treatment. Sample identity number is inserted into all data. All discrete data are stored, tabulated, and plotted as a profile-function of position along the traverse. Humanly observed data will be compared versus mechanically observed data, and significant discrepancies will be displayed.

b. Computer Program. The "Trend Following in Properties of Samples" Computer Program maintains an updated mathematical model of the variation of sample properties with geographic position and of the dispersion (variance) about mean values. The principal objectives of this program are to project or extend characteristic trends found and to detect statistically significant discontinuities in such trends, as being indicators of geological "contacts" between discretely separate geological units.

D. DATA FUNCTIONS UPON THE IMAGING DATA STREAM.

The flow of data within the mission-dependent portion of the Imaging Data Stream is shown in Figure 4-4. This diagram is related to Figure 3-4 and represents the Imaging Data Stream portion of that element in Figure 3-4 which is labeled "Mission-Dependent Subset of Telemetry Data Subsystem." Two types of arrayed data occur: photo-imaging (video) and laser radar data.

1. General Imaging Data Functions.

a. Data Functions. The following data functions are applied to all video Imaging Data:

(1) A selection capability will be provided to process either current real-time data or retrieved data.

(2) The identity of each frame, the time at which taken, the position of the LRV, and the camera identity and condition will be inserted into the data.

(3) The photo-imaging data will be displayed (TV) for initial visual check.

(4) Alarm conditions within the data will be detected and displayed.

(5) The gray-scale intensity reported by the camera will be transformed, according to the current model of need for intensity adjustment, into intensity data for display. The spatial distribution of the transform parameters will be displayed.

(6) Picture elements for which data are missing will be assigned a smoothed-interpolation value, and the location of such insertions displayed.

(7) Multiple pictures may be superimposed to reconstruct color effects.

(8) A plot-file of data for driving TV displays will be created.

(9) The plot-file will be stored (and can be retrieved upon demand).

(10) A capability to make hard copy photographs upon demand will be provided.

b. Computer Programs. The "Adjustment of Video Imaging Data" Computer Program provides image reconstruction, contrast expansion (contrast control), mean light-level adjustment, and signal reformatting, accommodates changes in pixel length, raster spacing, and bits/pixel, and enables stereo viewing.

The "Human Observation Recording and Assimilation" Computer Program provides for acceptance into the computer of information derived by geologists from visual study of the terrain and specimens of lunar material and for distributing such information appropriately. The geologist-observer inputs his observations to the computer through the medium of a keyed function-box, a light pen, and/or a console typewriter. The range of scope of such observations includes the identification of geological features of interest viewed by TV, annotations for the record and the topographic map as to the character of such features, the estimated scientific worth or value of investigating such features in detail, the scope or extent of the zone to be investigated in greater detail, the manner in which the investigation is to be conducted, the detail or level of resolution involved, and an estimate of the overall time required for execution. This program interfaces with and services the "Feature Investigation Management" Computer Program and the "Map and Profile Plotting" Computer Program.

2. Panoramic TV Camera Data Treatment.

The total input data associated with viewing the landscape through the Panoramic TV Camera are Panoramic TV Camera photo-imaging data

Figure 4-4. Imaging Data Flow Diagram

(including camera conditions), range data for superposition from the laser data, topographic reference data, geological feature humanly keyed data, and LRV position, from the Navigation and Guidance System

a. General Treatment.

(1) After the common data functions in paragraph D 1 a have been performed through step (7), the photo-image data will be corrected to remove geometric distortions in display [see (6) below], producing true-perspective viewing.

(2) A set of azimuth-and-elevation angle markers will be computed from knowledge of the LRV's heading and inclination, the attitude of the camera relative to the LRV, and the focal length of lens used. The set of markers will then be inserted into the data (for display)

(3) Apparent range lines (ground traces of a set of vertical cylinders of uniformly graduated radius) will be inserted into the data from a knowledge of the camera height and tilt (roll angle) and the terrain topography. Selectively, the terrain can be stipulated to be smooth (spherical).

(4) Standardized graphical representations of geological features, including framing of the "window" assigned for further photo-imaging investigation of geological features and actual range as determined by Laser Radar, will be inserted into the data from humanly keyed inputs.

(5) The silhouette of selected geological features as seen from the LRV will be computed from reference topographic data and inserted into the data.

(6) Panoramic TV Camera data will be displayed on a set of flat surfaces arranged to approximate the lower half of a spherical surface (the "Teacup").

(7) Using observed solar direction and reference topographic data, observed shadow patterns will be compared versus anticipated shadow patterns and inconsistencies displayed.

(8) Successive photo-images from the same camera position but with differing solar illumination angles and possibly with differing camera attitude will first be registered (brought to coincidence) by correlation and then differenced to create time-lapse difference-images.

(9) Using reference topographic data and the shadow pattern relationships developed in (7) above, the time-lapse difference-images created in (8) will be interpreted as corrections to the reference topography.

(10) Successive photo-images taken from neighboring viewing points whose separation is deduced from change in the LRV position will be analyzed photogrammetrically to determine the range of selected geological features.

(11) The range and azimuth to selected geological features, as found in (10) above, will be superimposed on the topographic map.

(12) Steps (8) through (10) of paragraph D. 1. a will be completed.

b. Computer Programs. The "Panoramic Display Range Indication" Computer Program provides superimposed data in the Panorama Display and Feature Investigation Display. Before any geological features have been identified and until range data to such features have been measured, there is shown in the Panorama Display scene a grid of lines corresponding to range and azimuth on a smooth, level lunar surface, with numerical value labels to each line. As geological features are identified and their range and elevation determined, such empirical data will be annotated in the Panorama Display. As laser coverage becomes available, the program will determine automatically the range and elevation to all significant peaks (where the parameters of "significant" can be altered in real time) and show these data on the display.

The "Projection Correction of Imaging Displays" Computer Program eliminates the persepctive distortion effects introduced by the indirect transfer (eccentric projection) of video data to panoramic displays.

3 Foreground TV Camera Data Treatment

The total input data associated with viewing through the Foreground TV Camera include Foreground TV Camera photo-imaging data (including camera conditions), geological feature humanly keyed data, and LRV position, from the Navigation and Guidance System

a General Treatment

(1) After the common data functions in paragraph D 1 a have been performed through step (7), the display mode is selected, discriminating between use of the Foreground TV Camera for monocular versus stereographic viewing

(2) In both display options in (1), the data are corrected for geometric distortion in the display, to produce true-perspective viewing

(3) Normal viewing of Foreground TV Camera images in the monocular mode is on screens perpendicular to the camera (or viewing axis)

(4) Foreground TV Camera images will also be displayed on the foreground screen of a Vehicle Simulator This screen, which is attached to the Simulator's front wheels and lies approximately in the plane representing the terrain surface, presents the Imaging Data in its proper spatial relationship to the LRV.

(5) Stereographic image pairs transmitted as a single split-image will be displayed monocularly on a single screen as in (3) above and viewed anaglyphically

(6) Stereographic image pairs transmitted as two completely separate images will be displayed on two separate screens set side-by-side and viewed anaglyphically

(7) In conjunction with stereographic images per (5) and (6) above, the range to selected geological features will be determined from knowledge of the separation distance between the effective viewing positions, deduced from changes in the LRV

position, the camera boom angles, or external anaglyphic mirror separation

(8) The horizontal component of the range in (7), coupled with its azimuth, will be plotted as a map function

(9) When used to study rock specimens, patterns in the specimen will be evaluated for selected pattern-models

(10) Steps (8) through (10) of paragraph D 1 a will be completed

b. Computer Program. The "Projection Correction of Imaging Displays" Computer Program eliminates the perspective distortion effects introduced by the indirect transfer (eccentric projection) of video data to panoramic displays.

4. Sample TV Camera Data Treatment.

The total input data associated with viewing through the Sample TV Camera include Sample TV Camera photo-imaging data (including camera conditions), and sample identity and pattern type, as humanly keyed data.

a. General Treatment.

(1) After the common data functions in paragraph D.1.a have been performed through step (7), the display mode is selected, discriminating between monocular and stereographic viewing.

(2) Stereo-pair Sample TV Camera photo images will be projected as a split image onto a single display screen and viewed anaglyphically.

(3) The particular values of the parameters in the mathematical model of pattern type will be determined

(4) The contact lines between pattern elements per (3) above will be overlaid (superimposed) upon the photo-image of the sample

(5) The distribution of grain size, angularity, and alignment in the specimen will be determined separately for each pattern zone

(6) Steps (8) through (10) of paragraph D 1 a will be completed

b Computer Program. The "Sample TV Camera" Computer Program provides the pattern recognition analysis and grain properties analysis described above

5 Laser Radar Data Treatment

The total input data associated with the Laser Radar are radial (vector) distance between Laser Radar and terrain feature reflecting laser pulse, pointing angles of Laser Radar (including imaging coordinates), adjustments to laser data furnished by Payload Engineering, elevation of the laser, furnished by the Science Data, selenographic coordinates of the LRV and its heading, from the Navigation and Guidance Subsystem, and identification of geological features for which range is needed and of traces through which a profile is needed

a General Treatment

(1) Frame identification and alarm detection are as in paragraph D 1 a
(2) Correction for deviations of the instrument conditions from nominal will be applied
(3) Difference in elevation between the reflecting point and the laser will be determined and combined with the LRV elevation to determine the elevation of the reflecting point
(4) Of the series of reflecting points which occur in any one raster-sweep of the laser, only those which lie on (or are interpolated to be on) standard elevations for contours are retained. These contour-crossing points are called "dummy points" and the set of dummy points for any one elevation defines that contour.
(5) The selenographic coordinates of dummy points will be found from combination of the position of the LRV plus the horizontal vector component of the radial distance from laser to reflecting point, and stored.
(6) A topographic map will be prepared by fairing smooth curves through the set of contour crossing points and plotted.

(7) Profiles through selected ground traces will be determined and plotted.

(8) Range to selected geological features will be determined by inspection of the stored topographic data and transferred to the Panoramic TV Camera for superposition in its field of view.

b. Computer Program. The "Map and Profile Plotting" Computer Program transforms the Laser Radar data from the vehicle into a topographic contour map of the visible area along the traverse and subsequently deduces (and displays) from the map vertical profiles of elevation along specified ground traces. The program produces related topographic data photogrammetrically from photo-imaging data taken from displaced viewing points and establishes a weighted-mean interpretation for ultimate use. Features identified visually by geologist-observers and recorded by function-box are annotated upon the map. The laser data presented to this program are replaced by contour-passage points interpolated to standard contour elevation, and contours are created by fairing smooth curves through the contour-passage points corresponding to any one given elevation.

E. DATA FUNCTIONS UPON THE PAYLOAD ENGINEERING DATA STREAM.

The flow of data within the mission-dependent portion of the Payload Engineering Data Stream is shown in Figure 4-5. This diagram is related to Figure 3-4 and represents the Payload Engineering Data Stream portion of that element in Figure 3-4 which is labeled "Mission-Dependent Subset of Telemetry Data Subsystem."

Payload Engineering Data include all measurements received from the LRV concerning the status or condition of the scientific instruments constituting the payload. Typical among these are the configuration or articulation of instruments and their position relative to the vehicle, their physical condition such as temperature, incident light, electromagnetic field, etc., and their resource value, such as battery charge and developable forces.

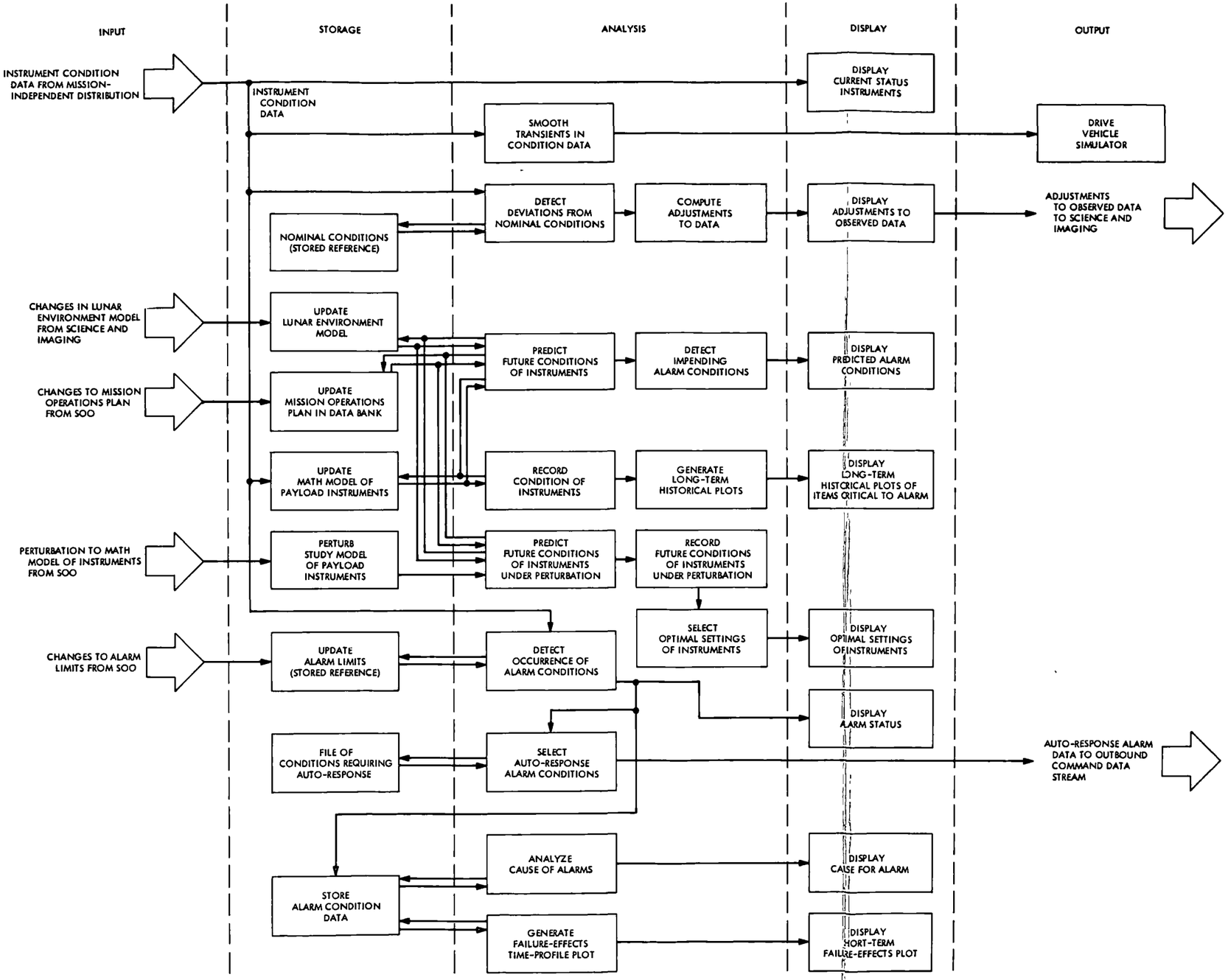


Figure 4-5 Payload Engineering Data Flow Diagram

1. General Payload Engineering Data Functions.

The purpose of Payload Engineering is to establish the validity of the data being received by the Science and Imaging Data Streams, to provide suitable interpretive corrections to it, to correct or minimize existing nonstandard instrument conditions, to detect impending alarms, and to optimize instrument utility or effectiveness. The considerations treated in Payload Engineering are common to all instruments. This section discusses the determination of current instrument conditions, adjustments to observational data, actual alarm conditions, impending alarm conditions, and the modification of instrument control settings to achieve greater effectiveness.

2. Current Instrument Conditions.

(a) The current value of instrument condition data received from the LRV will be displayed directly and will be used to update the mathematical model of the LRV which is maintained in the computer on a continuous basis.

(b) The "Payload Math Model" Computer Program maintains a data bank of current values of the numerical magnitudes of all descriptions of the LRV. This program interfaces with and services the "Control of Vehicle Simulator" Computer Program.

(c) The "Automatic Determination of Instrument Status" Computer Program accepts telemetered engineering data concerning the condition of each scientific instrument on the vehicle and of the environment in which the vehicle is operating. From these data it concludes the present status of well-being and adequacy of each instrument to perform its assigned tasks and projects (estimates) their ability to perform assigned tasks in the future. The program provides a comprehensive status display with simplified representation of overall status of the ensemble of all instruments, plus a diagnostic indication of the proximate and ultimate causes of any substandard conditions (malfunctions) which may arise and recommended courses of action to remedy the malfunction. This program also determines the adjustments (corrections) to observed data due

to deviations of instruments from standard conditions The program interfaces with and services the "Feature Investigation Management" Computer Program

(d) Rapid transients in the data will be smoothed. The configuration and attitude of the Vehicle Simulator will be kept slaved to such smoothed data. The "Control of Vehicle Simulator" Computer Program causes the Vehicle Simulator to follow, conform to, and coincide with the visible articulations of the LRV as it changes attitude and configuration, causes the photo-image of the foreground to be displayed on a planar screen tangent to the Simulator front wheels, and causes such screen to be tilted relative to the LRV at an angle which is representative of the natural slope of the lunar terrain at the current LRV location. This program interfaces with the "Control and TV Tracking of Science Instruments" Computer Program, "Map and Profile Plotting" Computer Program (for Laser Radar measurements from masthead to the foreground), and "Projection Correction of Imaging Displays" Computer Program.

(e) Historical plots of the behavior of selected instrument characteristics will be generated and displayed

3. Actual Alarms.

(a) The onset of actual alarm conditions will be detected by comparing direct observations versus their alarm limits. The results will be displayed immediately, notice of alarms sent to the Science and Imaging Data Streams, and the pertinent data relative to the alarm stored for analysis.

(b) Alarm data will be screened to detect those conditions which require automatic response (corrective action) and such information will be transferred to the Outbound Command Data Stream.

(c) Alarm data will be analyzed by computer to determine their proximate cause, first as to whether that cause is internal to the LRV or external to it and second, if internal, to determine its precise origin. Again, the results will be displayed.

(d) Plots of the critically affected properties, as functions of time, will be generated and displayed.

(e) The alarm conditions not requiring automatic corrective action will be analyzed and suitable correction action determined and displayed.

4. Data Validity and Adjustment.

(a) The condition of the instruments will be compared versus nominal values and the validity* of received data established. This validity data will be separated according to the instrument involved and sent to the appropriate Data Stream.

(b) The corrections to instrumental data which are required to adjust that data to nominal conditions will be computed for each instrument and sent to the appropriate Data Stream.

(c) The "Automatic Determination of Instrument Status" Computer Program described in paragraph E. 2. (c) is also used for Data Validity and Adjustment.

5. Impending Alarm Conditions.

(a) The computer-stored mathematical model of the Mission Operations Plan (MOP) will be updated to reflect the amendments to it instituted by the Science Operations Organization.

(b) The computer-stored mathematical model of the lunar environment will be updated to reflect the changes in it found from Imaging Data and Science Data.

(c) Future values of instrument conditions will be predicted by combining future operations (from the MOP) with the state of the payload and the lunar environmental conditions expected to be encountered.

(d) Alarm conditions inherent within the predicted future instrument conditions will be detected and displayed.

*Validity and alarm are not directly analogous See definitions in Appendix B

6. Optimization of Operating Conditions.

(a) Test perturbations of instrument control settings identified by the SOO will be introduced into the perturbed mathematical model of the payload for study purposes.

(b) Future values of instrument conditions under the perturbed control-settings will be predicted as in E. 5. (c).

(c) Critical-situation values of instrument conditions from (b) will be selected, and plots of their values as parametric functions of the studied perturbations will be generated and displayed.

(d) Optimal values of the perturbed control settings will be determined from (c) and displayed.

SECTION V
SCIENCE COMMAND DATA SUBSYSTEM

This section of the report describes the mission-dependent functions which are performed upon command data within the SGDS. The Science Command Data Subsystem (SCDS), whose relation to the SGDS was shown in Figure 3-2 is complementary to and supports the Science Operations Organization The separate data streams within this subsystem are first identified and then the data functions peculiar to each stream and the flow of data in that stream described. Communications from the SOO to the SCDS are designated herein as "instructions." Data sent from the mission-dependent portion to the mission-independent portion of the SCDS are designated as "command messages "

A. SCIENCE COMMAND DATA SUBSYSTEM FUNCTIONS

The functions which must be performed by the Science Command Data Subsystem are:

(1) Instructions from the SOO are to be interpreted and executed.
(2) Automatic-response alarms reported by the Science Telemetry Data Subsystem (which constitute instructions to the SCDS) are to be executed.
(3) Notice of forthcoming events as specified in the Mission Operations Plan, supplemented by the optional sequences which are currently foreseen, are to be displayed to the SOO.
(4) Routine activities within (3) (those not requiring human enabling) are to be executed.
(5) Suitable command sequences to accomplish (1), (2), and (4) must be determined.
(6) Check values to permit confirmation of execution of issued commands must be established.
(7) The command sequences in (5) must be transformed into command messages and issued to the Mission-Independent Command System
(8) Actual execution of issued commands must be confirmed.

B. COMMAND DATA STREAMS.

Two separate data streams occur in the Science Command Data Subsystem. One is the stream which originates in the Mission-Dependent SCDS, emanates outward to the LRV and is designated here as the "Outbound Command Data Stream" (OCDS). The other data stream flows in the opposite direction, returning evidence of proper compliance with issued commands, and is known as the "Inbound Command Data Stream" (ICDS)

C OUTBOUND COMMAND DATA STREAM FUNCTIONS.

The flow of data within the mission-dependent portion of the Outbound Command Data Stream is shown in Figure 5-1 This diagram is related to and represents the outbound portion of that element in Figure 3-4 which is labeled "Mission-Dependent Subset of Command Data Subsystem "

1 Instructions.

(a) Instructions received from SOO are first routed according to their impact upon the Mission Operations Plan (whether or not they amend that plan)

(b) Instructions amending the MOP require confirmatory authorization before being implemented After confirmation the amendments are inserted directly into the MOP

(c) If no suitable command set can be found, notice of this inability to comply with instruction will be displayed

2 Alarms

(a) Alarm data received from the Science Telemetry Data Subsystem are first separated, according to their urgency, into "incurred malfunctions" versus "impending malfunctions" and displayed as a status function

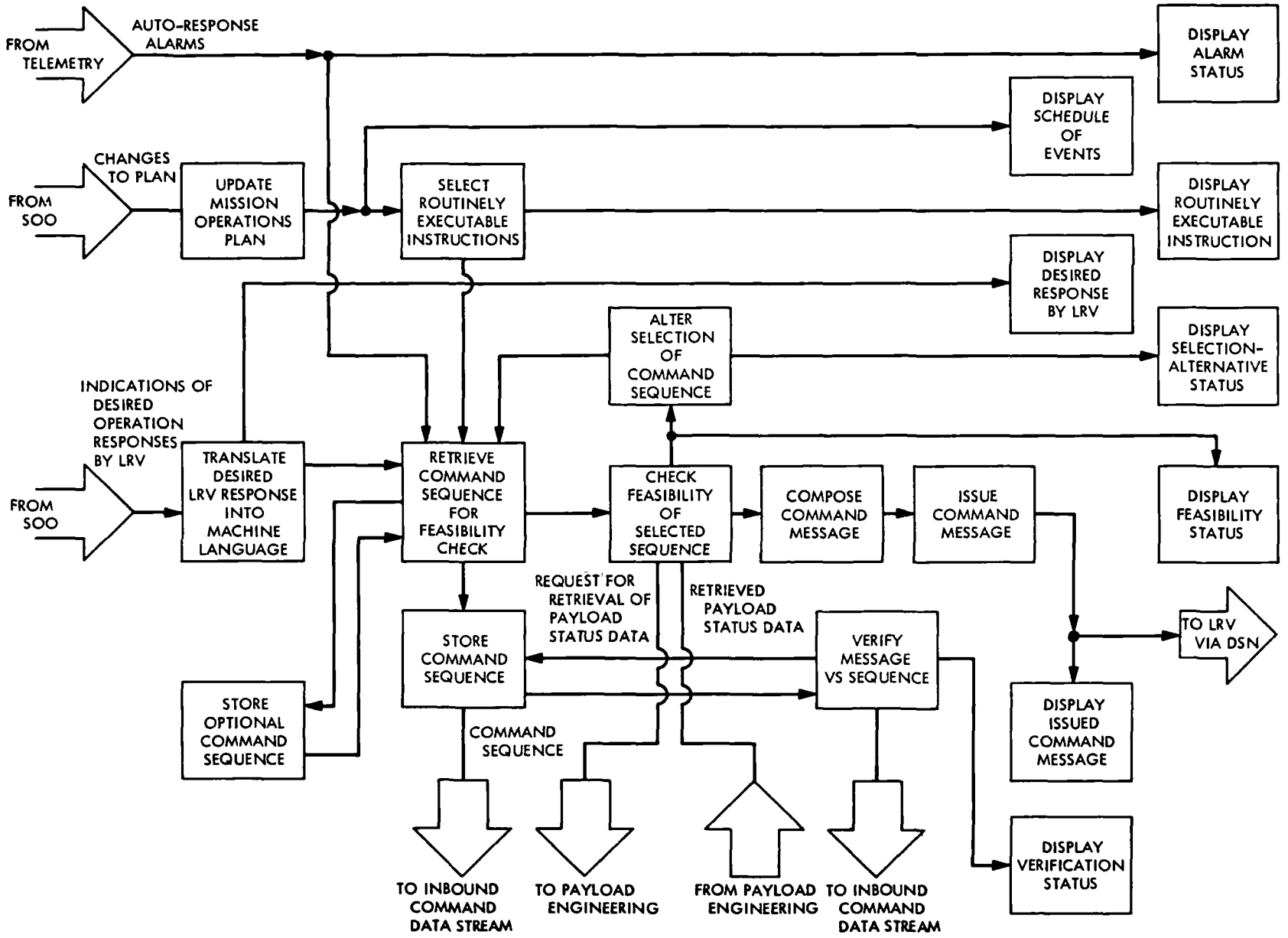


Figure 5-1 Outbound Command Data Flow Diagram

(b) Each alarm is compared versus a table of standard responses, the specified response implemented, and any consequent constraint-violations displayed

(c) Each alarm is analyzed to determine its cause As a first step, the cause suggested by the Science Telemetry Data Subsystem is checked and, if corroborated, the Science Telemetry Data Subsystem is notified If not corroborated, a more extensive search is undertaken. If no ascribable cause is found, the SOO is notified of this fact.

(d) The corrective action, if any, outlined in (c) above is implemented

(e) After corrective action is completed, the faulty condition is retested When the condition is no longer faulty, the alarm status is withdrawn.

(f) Data affected by the alarm are so placarded.

3. Mission Operations Plan Execution.

(a) All science operations are initiated by SOO instructions only.

(b) The science operations events which are scheduled in the MOP to be initiated in the near future will be displayed

(c) The current value of margins upon mission constraints will be computed and displayed.

(d) Quasi-steady trends in the margins upon mission constraints and estimates of times when constraints will become violated by quasi-steady trends will be computed and displayed

(e) Future values of all mission constraints, estimated on the twin bases of (1) normal execution of the MOP coupled with average lunar conditions and (2) adverse occurrence of random influences, will be computed and displayed

4 Command Sequence Generation.

(a) Instructions other than MOP amendments are first converted into candidate command sequences by direct tabular lookup

(b) The feasibility of the candidate command sequence is checked to detect obvious potential violations of constraints.

(c) If a violation of constraints would result from execution of the candidate command set, notice of this state is displayed and a search for a non-violating candidate command sequence is instituted.

(d) If and when a suitable non-violating command sequence is found, notice of its finding is displayed and the command sequence is transmitted as a command message.

(e) If no suitable command sequence can be found, notice of this inability to comply with the SOO instruction will be displayed and furnished to the Inbound Command Data Stream.

5. Command Initiation.

(a) The tracking station to transmit the command to the LRV will be selected

(b) Command messages will be stored and issued for transmission to the appropriate tracking stations

(c) Upon notice by ICDS of discrepancy in command message as received at the tracking station, the command message will be reissued

(d) Upon notice by the Inbound Command Data Stream of verification of valid receipt of command message by the tracking stations, authority to transmit will be issued.

(e) Upon notice by ICDS of discrepancies in command message as stored in the memory on board the LRV, the command message will be reissued.

(f) Upon notice by the Inbound Command Data Stream of confirmation of valid transmission of the command message by the tracking station and valid receipt and storage by the LRV, authority to execute ("enable") will be issued.

6. Computer Programs

(a) The "Science Command Generation/Verification and Traffic Control" Computer Program generates command lists for the accomplishment of a given task, validates such lists for internal compatibility and accuracy within the vehicle's data system, predicts the external effects of executing such sets of commands, institutes release of the commands to the DSIF, verifies accurate receipt of commands at the Deep Space Station (DSS), confirms proper transmission of the command and its receipt by the vehicle, enables execution of the command, monitors proper execution of the command, detects anomalies in execution, determines appropriate corrective action, and iterates

(b) The "Control and TV Tracking of Science Instruments" Computer Program determines the sequence of commands required to cause science instruments to be moved automatically from their present location to a desired (different) location relative to the vehicle, and causes the Foreground TV Camera to be kept trained (centered) upon the significant element of the subject science instrument as it moves. This program interfaces with and services the "Science Command Generation" portion of the "Science Command Generation/Verification and Traffic Control" Computer Program. The program pertains to all deployable science instruments on board the LRV and includes avoidance (preclusion) of physical interference between elements of the LRV

(c) The "Feature Investigation Management" Computer Program identifies optimal programs of activities to exploit the opportunities which are inherent in scientific discoveries (science opportunities), while maintaining the Mission Operations Plan and meeting all mission operations requirements and constraints. The program accepts all notices of opportunities for unscheduled scientific investigation which are presented to it, estimates their impact upon all resources (time, energy, temperature, etc.), establishes their value [based upon a weighted sum of

(1) the finder's appraisal and (2) formulaic evaluation based upon standard-value tables for cited properties of the feature], ranks the set of all opportunities in order of descending value per unit of increased time required (with cutoff when any other resource constraint is violated), and indicates the specific opportunities which can be explored within the time allowances made in the Mission Operations Plan for unscheduled science operations.

D INBOUND COMMAND DATA STREAM FUNCTIONS

The flow of data within the mission-dependent portion of the Inbound Command Data Stream is shown in Figure 5-2 This diagram is related to and represents the inbound portion of that element in Figure 3-4 which is labeled "Mission-Dependent Subset of Command Data Subsystem "

1. Verification and Confirmation

(a) Aborts caused by ground equipment will be detected automatically, and notice of such abort will be sent automatically to the SFOF for display.

(b) Command messages received by the tracking station will be stored and relayed to the SFOF

(c) The returned command message from the tracking station will be compared versus the issued command message. The results of this comparison will be transferred to OCDS.

(d) Command messages authorized to be transmitted by the tracking station will be monitored as they are transmitted by radio to the LRV and the monitored command message relayed to the SFOF

(e) The monitored command message in (d) will be compared versus the issued command message The result of the comparison will be furnished to OCDS.

(f) The content of the stored command message in the LRV, as read back to Earth, will be compared versus the issued command message. The results of the comparison will be furnished to OCDS.

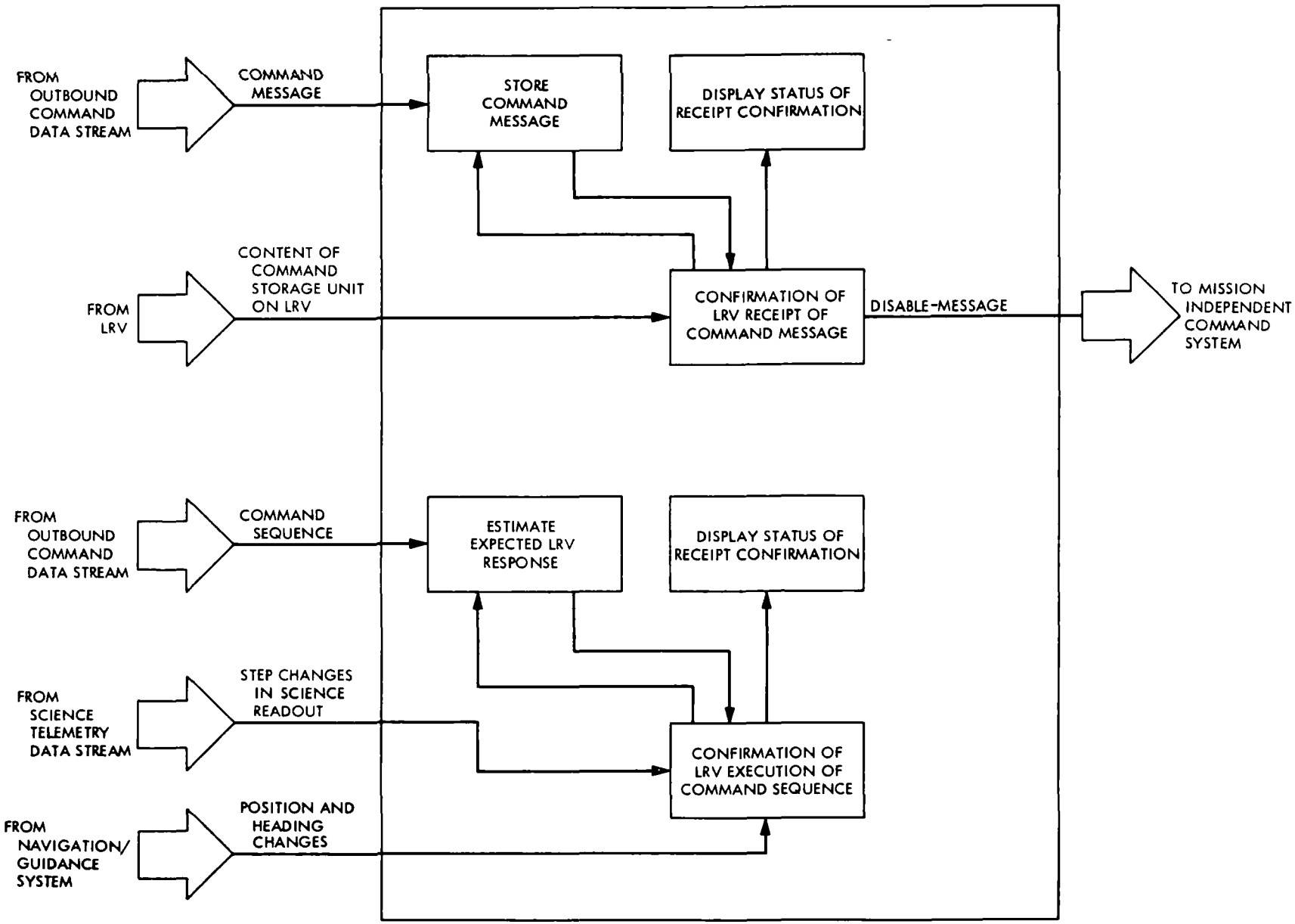


Figure 5-2 Inbound Command Data Flow Diagram

2 Execution Check-Value Generation

(a) Values of changes expected to occur in the observed data coincidentally with execution of scheduled command sequences will be computed

(b) The uncertainty in these changes will be computed

(c) The observable changes accompanying execution of the command sequence will be arranged in order of the amount that they exceed the uncertainty in the observation, normalized in terms of least detectable change in the observation

(d) A cutoff line will be established in the ordering of observable changes in (c), corresponding to the degree of confidence desired in assurance that the command sequence has been properly executed.

SECTION VI
SCIENCE OPERATIONS ORGANIZATION

The Science Operations Organization (SOO) comprises the mission-dependent operational personnel required for the support and conduct of LRV science operations The functions and organization of the SOO are the subject of this section

A. FUNCTIONS OF THE SCIENCE OPERATIONS ORGANIZATION

LRV science operations are defined as those operations directly related to the control of the LRV science payload and the acquisition of science data. To the extent that science data analysis is relevant to the control or data acquisition problems, then data analysis is an operational function On the basis of this definition off-line non-real-time functions are not included within the science operations considered in this section. For example, post mission data reduction, enhancement, and analysis functions are not included

The SOO carries out its operational functions in accordance with the Mission Operations Plan It utilizes the combined capabilities of the LRV, its science instruments, and the Science Ground Data System. There are five basic operational functions for which the SOO is responsible These are listed as follows (not necessarily in order of priority or importance):

(1) Determination of the engineering status of each science instrument
(2) Determination of how each instrument is to be utilized during the conduct of science experiments.
(3) Analysis and interpretation of science data (to the extent that the results affect subsequent operations)
(4) Determination of command functions required to obtain desired LRV instrument responses, parametric changes, readouts, etc.
(5) Maintenance of liaison, information flow, and mutual support both within the SOO and between the SOO and other operational groups (within the Mission Operations Organization).

Each of these basic functions of the SOO is described in the following paragraphs.

1. Engineering Status of Instruments

Real-time engineering status of the science instruments is determined through the following functions

(a) Determination of the present capabilities of each instrument based upon engineering telemetry data received
(b) Assessment of the limitations and constraints on instrument use as a function of the instrument's design and its present capabilities
(c) Determination of the instrument's performance and its effects on the data
(d) Generation of corrective action required in the event of instrument malfunction
(e) Evaluation of proposed instrument use, given the instrument's present capabilities and limitations

2. Instrument Use

How the science instruments are to be used relates to instrument parameters, modes, pointing angles, etc , as required for the science experiments. This function is incident to, and directly follows, the experimenter's decision as to what to do Given what is required by the experimenters and the instruments' capabilities and limitations, instrument use is decided Optimization of data yield and minimization of experiment durations are governing, and perhaps competing, objectives for such use determinations

To a great extent instrument use can be planned prior to launch on the basis of environmental models, experiment design, and instrument design However, real-time overrides of the planned use must be possible in the event of instrument malfunction, unforeseen environmental condition, or unusual scientific opportunity.

3. Analysis and Interpretation.

Analysis and interpretation involves scientific calculations and judgments on the science experiment data received through the SGDS The yield is new information about various characteristics of the lunar surface. In addition, this function continuously determines what the subsequent course of science operations should be. This requires the application of scientific judgment, in real time, to a complex set of factors including

(a) New information acquired and its relative value
(b) Present circumstances and scientific opportunities
(c) Pre-established science objectives
(d) Pre-established science experiment priorities
(e) Advantages and risks related to alternative courses of action

4. Origination of Required Command Functions

The command process begins with determination of what vehicle or payload responses are required (provided, of course, that such responses are within the commandable capability of the LRV and its payload) The required responses typically relate to the readout of instruments, manipulation of instruments, change of parameters, assessment of instrument malfunctions, selection of telemetry modes, and LRV movement.

Among the required capabilities of the Science Command Data Subsystem is the capability to translate automatically the desired LRV and payload responses into transmittable command messages (see Section V). However, the SOO must also be able to originate human override or backup commands. The function of determining the particular command functions required to obtain desired responses must be distinguished from human functions involved in command execution. SOO command execution functions are included within the basic liaison and support described in the next paragraph. Such functions include command data entry, command status monitoring, and command process control.

5 Liaison and Support Functions.

The effective performance of an operational group requires a high degree of liaison and coordination both within the group and with other operational groups in the operations organization. A continuous flow of technical and operational information between personnel and groups must be maintained

The support functions include all services provided to operational personnel which relieve them from tasks not directly related to their primary functions. These support functions include

(a) Monitoring of data flow within the SGDS
(b) Operation of computer programs
(c) Interfacing with DSN support personnel
(d) Execution of command functions in conjunction with DSN, e g., command information entry, command message generation, verification

B. CANDIDATE SCIENCE OPERATIONS ORGANIZATIONS.

Two candidate Science Operations Organizations are described in the following paragraphs Either organization will provide the total set of operational functions described in paragraph A. The differences lie in the distribution of the functions among the operational groups within the SOO The two organizations are described at the same level of detail as the functions referred to above. A more detailed SOO design will be developed in Phase B of this study as information relative to the science experiments and instruments becomes more definite

1 Plan A.

The first candidate organization (designated as Plan A) is depicted in Figure 6-1.

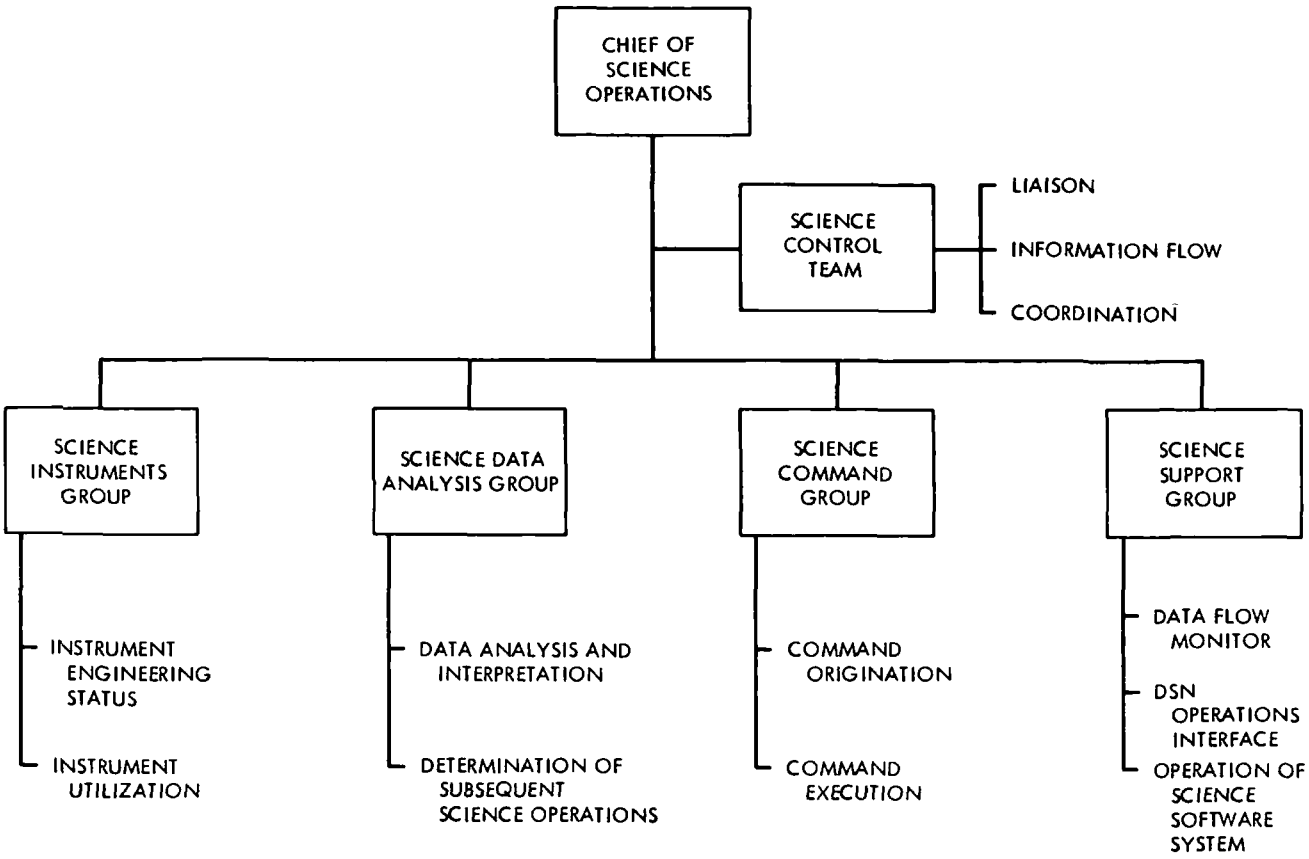


Figure 6-1 · Plan A for the Science Operations Organization

a Chief of Science Operations and Science Control Team The Chief of Science Operations (CSO) is responsible for the overall direction of science operations activities He reviews and approves all significant decisions bearing on the attainment of science objectives; he is aided in this task by a Science Control Team Together they provide the liaison and coordination function described in paragraph A 5 The CSO reports to the Chief of Mission Operations

b Science Instrument Group The Science Instrument Group is assigned two of the basic SOO functions· (1) determining the engineering status of the instruments and (2) determining the utilization of instruments as required for the science experiments. These functions are described in paragraphs A 1 and A 2, respectively. The rationale of this distribution of functions is that it places within one operational group all functions related to the science

instruments. This approach eliminates an operational interface between instrument engineers and instrument users.

The Science Instrument Group is, in effect, a service group to the Science Data Analysis Group (described below), i.e., the instrument group implements the science functions required by those conducting the science experiments by determining the use of the instruments within the capabilities and limitations of those instruments. However, this group does not originate the command functions required for instrument utilization or engineering status. These functions are provided by the Science Command Group. The Science Instrument Group provides the desired LRV and instrument responses to the Science Command Group for implementation (see paragraph B. 1 d below)

c. Science Data Analysis Group The Science Data Analysis Group provides the analysis and interpretation functions described in paragraph A 3. It is this group which provides the scientific judgment as to the course of subsequent science operations.

d Science Command Group. The Science Command Group originates all required command functions, given the LRV and/or instrument responses desired by other elements of the SOO. This group provides a centralized command operation—including both command function origination (paragraph A.4) and command execution functions.

e Science Support Group. The Science Support Group provides the support described in paragraph A. 5 except for command execution by the Science Command Group.

2 Plan B.

The second candidate organization (designated as Plan B) is depicted in Figure 6-2.

a Chief of Science Operations and Science Control Team The functions of these elements of the Plan B SOO are the same as described above for Plan A

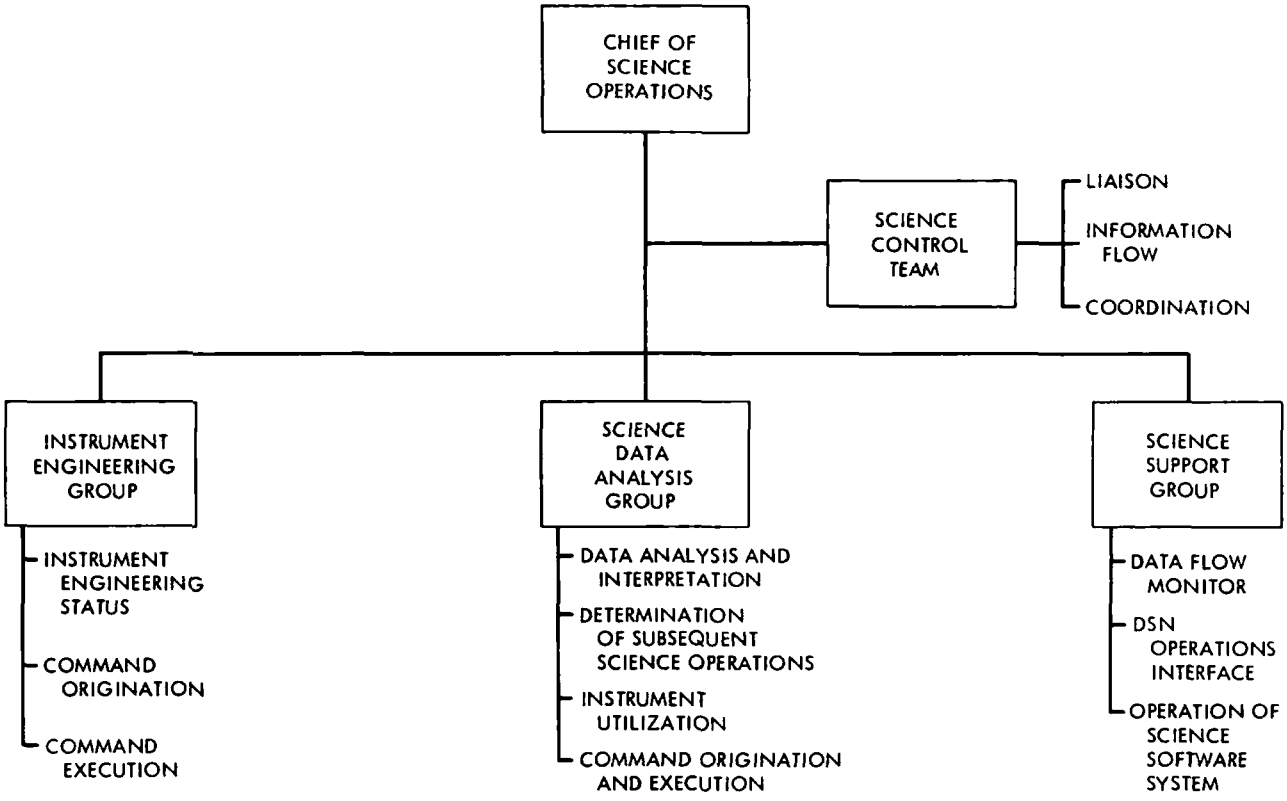


Figure 6-2 Plan B for the Science Operations Organization

b Instrument Engineering Group. The Instrument Engineering Group is assigned the basic function described in paragraph A 1, to wit, the determination of the engineering status of all instruments In addition, this group originates all command functions related to the engineering status of the instruments (e. g., commanding engineering data modes or correcting instrument malfunctions). The group also performs the associated command execution functions.

c Science Data Analysis Group. The functions of the Science Data Analysis Group in Plan B are the same as in Plan A with one important addition In Plan B this group also provides the instrument utilization function Under this approach the operational personnel responsible for instrument utilization work directly with the science experimenters whom they support. It becomes essential that the Instrument Engineering Group's determination of instrument engineering status be made available at all times to the Science Data Analysis Group.

The Science Data Analysis Group originates all command functions related to the utilization of the instruments for execution of the science experiments It is thus seen that an essential characteristic of Plan B is the decentralized organization with respect to science commanding (in contrast with the centralized approach of Plan A)

d Science Support Group The Science Support Group provides the same functions as in Plan A.

SECTION VII
PROBLEM AREAS

The following discussion of potential problem areas has been prepared to identify those factors which will introduce risk in preparing the mission operations design approach during Phase B. Many of these problems involve specification of information by external agencies and cannot be finally resolved until such information has been specified. The potential problem areas can be grouped into three categories: Mission Operations Planning, Ground Data System Design, and Mission Operations Organization. These categories will be discussed in sequence It should be noted, however, that while these problems can be grouped into three major areas, most of them impact all of the areas to some degree.

A MISSION OPERATIONS PLANNING.

The planning of mission operations necessarily influences the GDS hardware implementation and vice versa. In order to proceed with the Phase B effort, certain basic assumptions regarding the conduct of mission operations will be necessary. Also, certain facets of the design must proceed in either cursory or generalized fashion due to lack of precise knowledge or to allow flexibility in defining the eventual mission operations approach. The areas of risk involved are defined below.

1. Manned Mission Interfaces.

It has been assumed that the interface between the manned and remotely controlled operations is defined such that these operations are separate in time. If this assumption proves invalid, the GDS hardware and organization will be affected. For example, operating modes could be required where man would assist in vehicle operation by manipulation of the steering and driving controls, but Earth-based control would be necessary for video pictures, laser ranging, and scientific data analysis.

2 Mission Definition Schedule

Since definition of the mission will necessarily occur later, some eventual mission requirements will not, at the completion of Phase B, have been studied The impact of unstudied mission operations aspects upon the MOC design could be severe For example, the use of laser ranging from the Earth to supplement RF tracking for position locating, a concept recently discussed, could involve interfaces between ranging observatories and the operations center Also, the deploying of Remote Geophysical Monitors (RGMs) and their activation, monitoring, and operation are aspects which are presently undefined, the MOC interfaces will, therefore, have to be loosely defined

3 Time-Line Analysis on Rudimentary Level

One of the important tasks associated with the mission operations system-engineering effort is the preparation of a time-line analysis This analysis would verify whether the LRV mission operations tasks could be accomplished within the time allotted. Long hold-time requirements for laser range finding, gyro drift checks, and RF tracking, for example, could be evaluated for practicality and compatibility with the overall mission requirements Since many elements of the mission operations will evolve with vehicle development, the initial time-line analysis will have to be accomplished on a somewhat rudimentary level.

4 Lack of Consideration of Nonstandard Events

Since the mission definition will evolve with time, the initial nonstandard events studies will also be somewhat rudimentary in scope

B. GROUND DATA SYSTEM.

The GDS design study must assume, where data are unavailable, certain solutions to design problems and interfaces This imposes some risk on the success of the ultimate design This section details some areas of risk that have become apparent as the design has progressed

1. Payload Definition for LRV.

Scientific sample acquisition, storage, retrieval, analysis, etc. is an area requiring both ground and vehicle hardware, yet definition of the vehicle portion of this hardware is expected to come late in the development sequence

2. DSN Interface

The GDS design has proceeded on the basis that the DSN will have its Mark III system for command data handling operational. This assumes a certain LRV schedule. The impact on the GDS design if the Mark III system were to be unavailable has not been evaluated.

3. Command Traffic.

LRV commanding or executive control, coordinating the functions of scientific payload control, course control, spacecraft performance analysis, and mission operations, may involve interfaces beyond the scope of the Phase B study.

4 LRV Performance Analysis Requirements on GDS.

The Ground Data System may have to perform significant LRV performance analysis functions not considered in present studies. As an example, it is possible that video enhancement techniques would be useful in processing data from an unstabilized video system.

5 GDS Functional Design Feasibility Not Fully Tested

Not all of the GDS design approaches recommended for the Phase B effort will have been tested for feasibility. The basis for these recommendations will, for the most part, be grounded on study efforts as opposed to laboratory/breadboard verifications. As examples, it will be difficult to verify the definition and use of landmark reference data for position fixing use.

Resolution of the lunar surface for mapping purposes varies from 3/4 of a kilometer to 5 meters with most of the front face of the Moon mapped to 60-100-meter resolutions. Topographical/geological translations of this data will, of course, be necessary. Also, three dimensional modeling of the vehicle/science payload/terrain/celestial environment may be extremely useful for position assessment, thermal profiling, etc It will be necessary to assume that the mapping and modeling techniques will be adequate for the purpose intended.

C MISSION OPERATIONS ORGANIZATION

Some areas of the Mission Operations Organization will be lacking in specifics in structure and/or procedures, pending definition of missions and vehicle designs. Those areas which can be identified as requiring a more generalized approach are discussed below

1. Science/Navigation-and-Guidance/Vehicle/Mission Control Real-Time Interfaces

The operational structure for this area can be identified, however, the procedures suggested can be only guidelines As an example, the output of the video system is required at one time or another by all the above organizations, but it may be desirable to have a single section of the organization control the video system at all times This aspect may be difficult to decide without full mission and vehicle definitions.

2 Science Operations Execution Real-Time Interfaces

Procedures for these interfaces may be difficult to establish. As an example, the power and thermal budgets to science and to traverse operations could be allocated separately Computer programs could locate the instantaneous positions on these budget curves for individual assessment.

3. Organizational Flexibility.

It is obvious from previous experience and from the definition of the mission to date that the organization must accommodate, on short notice, drastically different mission modes with minimum delay and over long time periods The areas in which flexibility should be allowed and rigidity maintained are dependent upon vehicle and mission definition As an example, the Science/Navigational-and-Guidance interfaces could be formal on traverse, and informal (under the direction of Science) at science sites. In this case, the exact method by which targets of opportunity are to be designated and investigated needs to be established

4. Personnel Training

Full definitions of the mission and vehicle are, of course, needed before one can specify fully the personnel training, methods, and simulators that will be required.

5. LRV Vehicle Performance Analysis Organizations

Analysis of the LRV vehicle performance is a necessary function of the Ground System, but organization for this function may have to be assumed, or options kept open, during the Phase B study.

SECTION VIII
IMPLEMENTATION PLAN

A. SCOPE.

The implementation plan for the Science Ground Data System and Science Operations Organization (SGDS/SOO) covers the functional design/definition, development, and test planning/testing of the system. It specifically covers only the Science Ground Data System and Science Operations Organization and excludes all provisions for vehicle performance analysis, Navigation and Guidance, and integration/coordination with principal investigators, vehicle integration and project coordination

The present state of the functional design permits only general directions for implementation planning at this time. At the end of Phase B, as required by Reference 9, a more detailed plan will be prepared

B. BASIC ASSUMPTIONS.

The implementation plan is based on the following assumptions:

(1) This plan and cost estimate is limited to activities from design through pre-launch operations; no mission operations costs are included.
(2) Space flight operations control is assumed to be exercised from JPL
(3) The Deep Space Network Mark III will furnish the mission-dependent elements (MIE), hardware, software, and operations support (Reference 5). No mission-dependent elements (MDE) are required at field stations.
(4) No mission simulation is included for functional acceptance or operational training tests.

(5) The mission is presumed to consist of the deployment and operation of one vehicle.

(6) Launch is assumed to occur in the last quarter of calendar year 1973.

C. FUNCTIONAL DESIGN/DEFINITION.

The preliminary functional design of the Science Ground Data System, Phase A level, is contained in Sections III, IV, and V of this report The Phase B study will refine these functional design requirements and merge them with the functional design of the Navigation and Guidance System

Following the Phase B study, a design team will be established, composed of representatives from the Mission Operations System (MOS) and the vehicle agencies, to review and finalize all the functional design requirements within the guidelines and constraints established for the design The result of the design team effort will be the final specifications for the functional requirements of all SGDS/SOO ground-based elements associated with the LRV through pre-launch testing No physical configuration or performance allocations will be assigned by this design team to any specific hardware or software elements

D. DEVELOPMENT

The development phase of the implementation plan will involve the detailed design, preparation of specifications, and procurements of all hardware and the preparation of all software and operating procedures. The MOS will prepare the inputs required to officially request the MIE in accordance with the Project schedule and support plan. MIE development is the responsibility of the (Project) Tracking and Data System.

The MDE development will be divided into the three areas of hardware, software, and operations, and a design team will be established for each area responsible to the MOS. All MDE will be governed by Project schedule and documentation requirements.

During the development period, close liaison must be maintained between the agencies responsible for mission operations and all other LRV Project agencies to assure functional and physical interface compatibilities. The MOS and (Project) Tracking and Data System Managers will jointly share the responsibility that mission-dependent equipment delivery and installation schedules and facility beneficial occupancy are compatible with Project requirements MOS/Systems interface control documents will be prepared.

An analysis of the preliminary functional design requirements of the SGDS/SOO contained in this report leads to the following, first-cut list of MDE requirements.

1. Mission-Dependent Hardware.

The mission-dependent hardware elements presently definable are:

(a) Panoramic Television Display (1)
(b) Vehicle Simulator (1)
(c) Function Boxes (2)
(d) Science Command and Control Console (1)
(e) Stereo Imaging Devices (6)
(f) Analysts' Consoles (10)

2. Mission-Dependent Software.

The mission-dependent software elements required by the SGDS/SOO are:

(a) Science Command Generation/Verification and Traffic Control
(b) Sample Storage Filing Data
(c) Prior-Sample Search and Comparison
(d) Feature Investigation Management
(e) Control and TV Tracking of Science Instruments
(f) Analysis of Sample Constituents

(g) Map and Profile Plotting
(h) Magnetic Sources Location
(i) Panoramic Display Range Indication
(j) Trend-Following in Properties of Samples
(k) Automatic Determination of Instrument Status
(l) Human Observation Recording and Assimilation
(m) Control of Vehicle Simulator
(n) Projection Correction of Imaging Displays
(o) Adjustment of Video Imaging Data
(p) Payload Math Model
(q) Gravimetry
(r) Seismic Analysis
(s) Sample TV Camera (program)

3. Mission-Dependent Operations Plans/Procedures.

The following operations plans/procedures must be developed:

(a) Science Ground Data System and Science Operations Plan
(b) Space Flight Operations Plan
(c) Operating Procedures for MDE

E. TEST PLANNING/TESTING.

The entire test phase will be the responsibility of the MOS. A master test plan will be prepared which will define all test classifications and objectives, establish test designation nomenclature, and assign Project system responsibility for the generation of subordinate test plans and individual test design, documentation, implementation, and evaluation. To properly coordinate all phases of the MOS master test plan, close liaison must be maintained between MOS and the mission test and facilities working group.

Test planning shall be implemented by a building block approach starting with engineering, compatibility, and local operational training tests, then

through functional performance acceptance tests, and culminating with inter-facility operational tests to demonstrate that the Mission Operations Complex (MOC) is properly integrated and that effective performance has been achieved by trained personnel using proven operating procedures.

The test phase is divided into the following periods:

(1) Separate and joint engineering and compatibility tests.
(2) Functional performance acceptance tests
(3) Local operational training and inter-facility training and readiness tests

During the first period, the MOS and (Project) Tracking and Data System Managers are responsible to ensure that both the separate and joint MDE/MIE tests are properly identified, planned, executed, and evaluated to meet the overall development requirements of the MOC. The functional performance acceptance tests ideally will be performed by the MOS during the second test period, using a replica of the LRV to verify that the MOC is fully compatible with it and that all subsystem functional performance requirements have been met. In addition, the MOS is responsible for carrying out the inter-facility operational training and readiness tests during the third test phase. The (Project) Tracking and Data System manager develops the operational training test plans for all deep space communications centers (DSCCs).

The five major test classifications that have been established for the MOS master test plan are engineering, compatibility, functional performance acceptance, local operational training, and inter-facility operational training and readiness tests. A description of these classifications, their objectives, and relations is given in Appendix F, "Test Classifications."

F. SCHEDULE AND COST ESTIMATES.

The implementation of a Mission Operations Complex requires close coordination between the MOS and (Project) Tracking and Data System to assure

that all subsystems have met their functional performance specifications and are fully compatible with the LRV. The Project management is expected to provide timely directives so that the SGDS/SOO will be properly implemented in consonance with the overall Project schedule and requirements.

The SGDS/SOO Implementation Schedule is shown in Figure 8-1. It lists a few of these major Project milestones upon which the implementation of this system depends. Other major milestones such as the completion of the MIE/MDE Control Document and the MOS/Systems Interface Control Document, will be shown when the Phase B study is completed.

Figure 8-2 shows that the total estimated cost of the SGDS/SOO, to pre-launch readiness status and with the scope limitations as defined in paragraph A and B, is $3,660,000. The development will require a phased manpower buildup from one engineer as at present to 16 at the beginning of 1973. To meet the assumed flight schedule a maximum budget of $1.50 million is required for fiscal year 1971.

This cost estimate is an extrapolation based on a payload Science Ground Data System complexity approximately equivalent to that required for a Mariner spacecraft and a level of functional capability equivalent to a spacecraft test environment. The uncertainty in the cost estimate is believed to be less than 25%. It should be reiterated at this time that no costs for MIE are included and that no MDE at field stations has been assumed. The buildup of manpower to a pre-launch strength of 16 persons and the hardware and software requirements defined herein are based on experience in analyzing the functional design requirements of similar ground data systems and the organization necessary to develop and bring them to operations readiness.

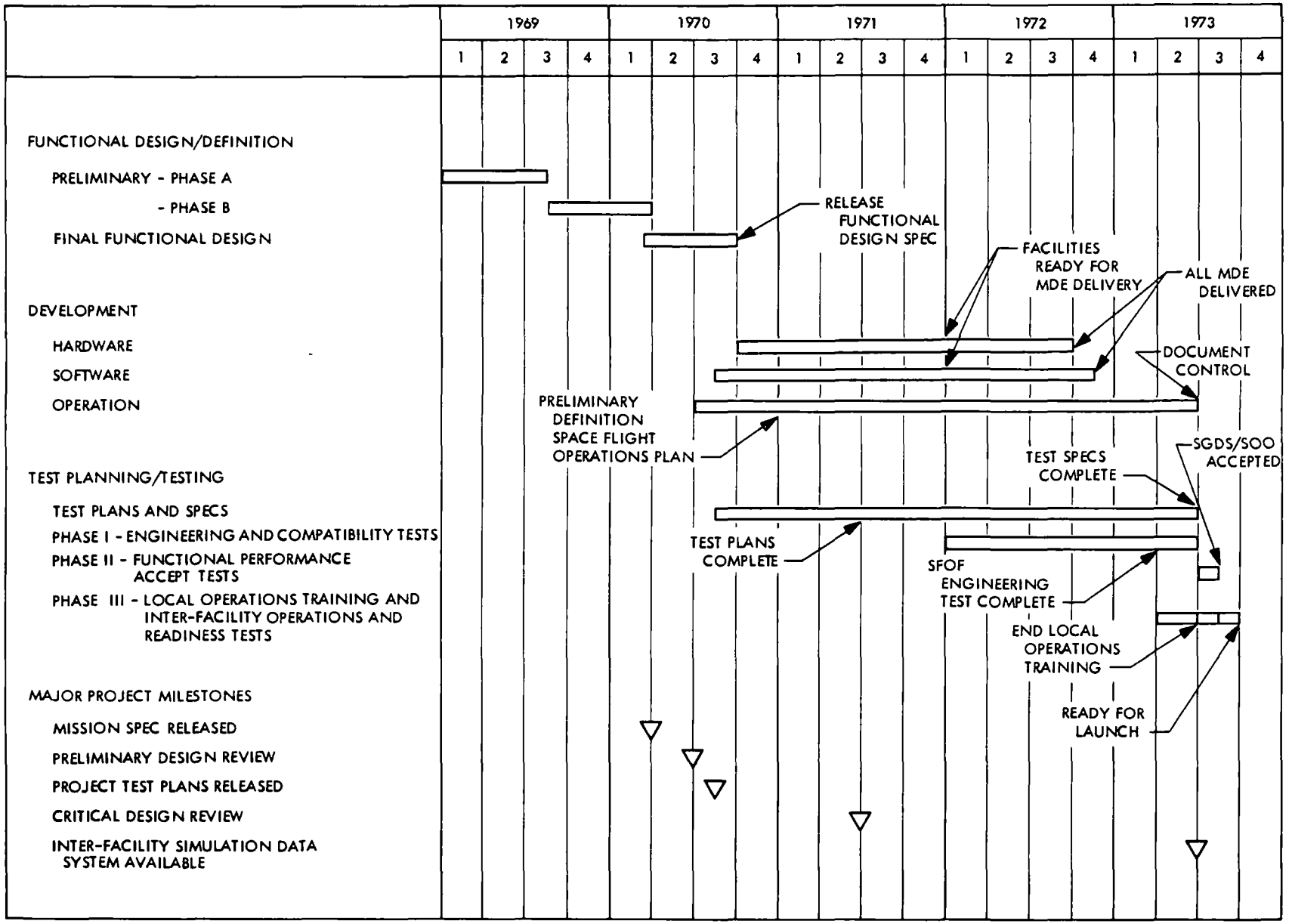


Figure 8-1. Implementation Schedule for the Science Ground Data System and Science Operations Organization

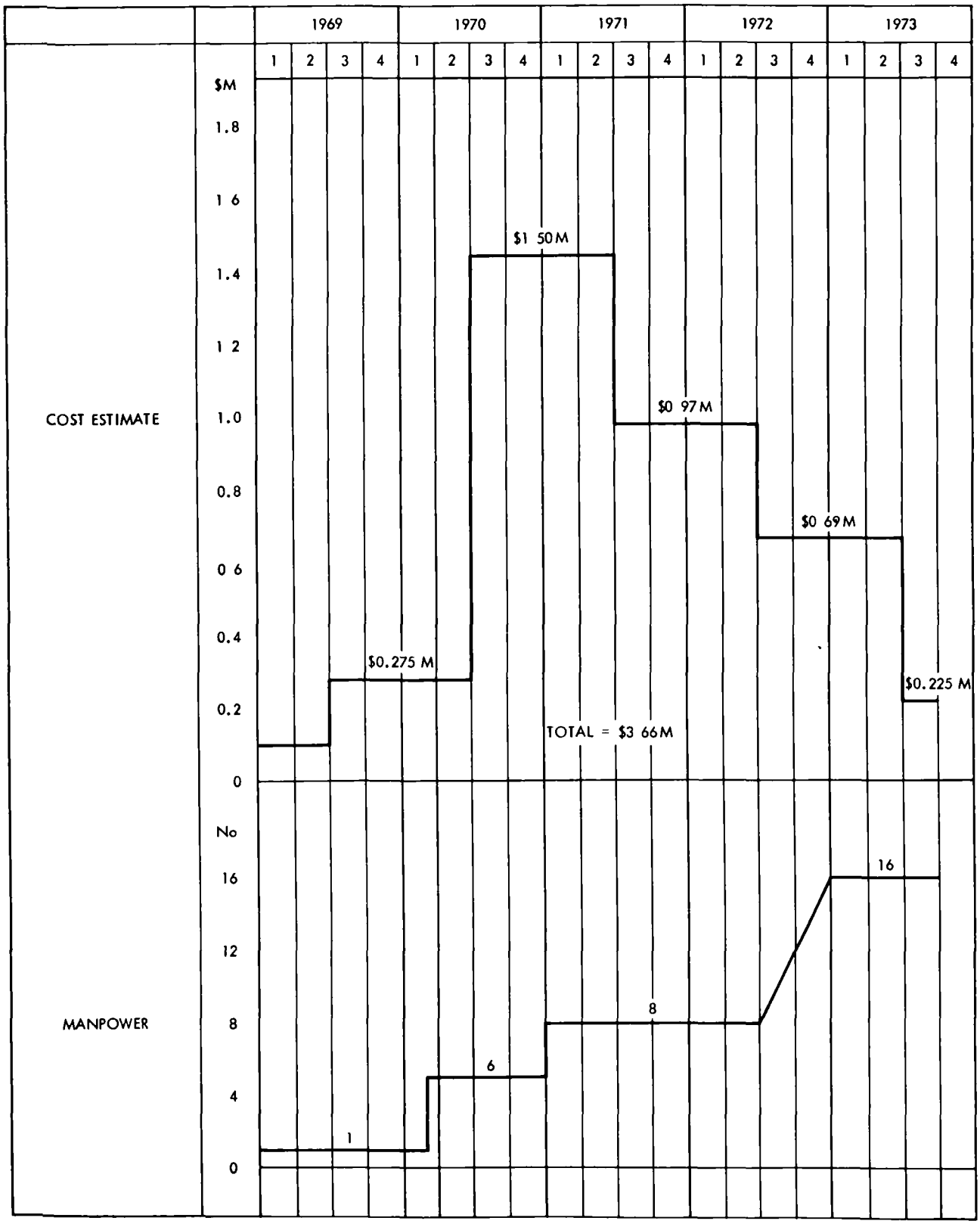


Figure 8-2. Cost Estimate and Manpower Schedule for the Science Ground Data System and Science Operations Organization

SECTION IX
CONCLUSIONS

A. TECHNICAL FEASIBILITY.

In the operations concepts and the functional design considered in this study of the Remotely Controlled Lunar Roving Vehicle Mission, no factor has appeared which would deny ultimate feasibility of the mission and which could not be surmounted by reasonable amounts of research and development effort.

B. IMPLEMENTATION.

It is estimated that the Science Ground Data System and the Science Operations Organization capability described herein for the Remotely Controlled Lunar Roving Vehicle Mission can be achieved (i.e., designed, developed, and tested) in a period of approximately four years, at a total cost of approximately $3.7 million, with a fiscal-year 1971 budget of $1.5 million. Manpower requirements would grow from one man at the onset to 16 men at launch readiness.

C. SUPPORTING RESEARCH AND TECHNOLOGY.

Supporting research and development efforts in the following ground-support areas are necessary in order to develop the technical capabilities required by the LRV Mission:

(1) Study modes and techniques in sampling operations, to provide effective acquisition of samples, coordinated TV coverage of acquisition, determination of sample properties, logical decision regarding sample retention, and stores management.
(2) Study modes and techniques in human assessment of terrain features through the use of television pictures, to establish the desirable

relations between types of photo-imaging (quick-look, panorama, and detail), superimposed frames of reference, effective and distortion-free display, and means of putting human observations into the computer system.

(3) Study modes and techniques in determining economical exploitation of scientific opportunities encountered.

(4) Study modes and techniques in translating laser radar image data into topographic contour maps.

(5) Study modes and techniques in rapid assessment of the composite condition of the total payload and in readily assimilable displays of payload condition.

(6) Study modes and techniques in deducing both the elevation of the LRV and its radius from the lunar mass centroid from the redundant observations upon them.

SECTION X
PHASE B STUDY PLAN

A. OBJECTIVES.

(1) To continue participation in studies of the LRV Mission, Vehicle, and Science Payload for the purposes of:

(a) Identifying and supporting constraints derived from LRV mission design.
(b) Determining the principal vehicle and science payload interfaces with the remotely controlled lunar operations, and recommending changes, as appropriate, to optimize system performance and scientific returns.
(c) Establishing preliminary interfaces between the manned and remotely controlled portions of the LRV Mission.

(2) To utilize the Phase B LRV Mission/Vehicle/Payload baseline, specified criteria, and results of the Phase A effort to establish, for the remotely controlled portion of the LRV Mission, the LRV operations design definition:

(a) The general functional design of the Ground Data System.
(b) The general functional definition of the Mission Operations Organization.
(c) The general Mission Operations Plan consistent with, and in support of, LRV mission design.

(3) To generate a plan which outlines the implementation of item (2) above, including completion of functional design, development, and test.

B. STUDY APPROACH.

1. Establishment of Constraints and Interfaces for LRV Operations Design/Definition.

This information will be derived from interaction with mission design activities, vehicle design and vehicle operations design activities, science experiments design/definition activities, and DSN design of the Mark III System.

a Mission Design Activities Science objectives are assumed as the focal point of mission design The present mission plans are confined to operation of a single remotely controlled vehicle at any given time, except that consideration will be given to backup support of manned operations Other factors derived from these activities which are of significant influence on the operations design/definition include.

(1) Time required for lunar traversal according to distances between targets of opportunity.
(2) Basic methods of lunar traversal, as dictated by terrain between targets of opportunity.
(3) Required minimum continuous operating periods.
(4) Required operating periods, if any, during thermally critical periods of the lunar day (i.e., lunar noon and lunar night).
(5) Minimum required data-accumulation rate.
(6) Minimum required commanding rate, as determined by specific mission requirements.
(7) Frequency and duration of vehicle stops as may be required for scientific investigation.
(8) Required operational flexibility as dictated by probability of discoveries in real time of new targets of opportunity.

b. Vehicle Design and Vehicle Operations Design Activities. A list of factors derived from these activities which are of significant influence include·

(1) Capability of hazard detection
(2) Vehicle mobility
(3) Vehicle stability
(4) Power budget
(5) Thermal limitations
(6) Information bandwidth
(7) Navigation instrument accuracies

c. Science Experiments Design/Definition Activities. The focal point of these activities is assumed to be at JPL. Factors derived from these activities which are of significant influence include:

(1) Complexity of operating two or more science instruments simultaneously.
(2) Interaction between science experiment requirements and navigation/guidance requirements.
(3) Problem of indexing and logging science samples and data.
(4) Science experiments interface, exemplified by conflicting requirements of operation at a specific location or specific time of the mission.

d. DSN Design of the Mark III System. Factors derived from this activity which are of significant influence include:

(1) Information transmission rates
(2) Link backup capabilities
(3) Expediency of information transmission
(4) Information threshold detection capability
(5) Information error reduction capability

Reasonably attainable modification to the system, which might significantly improve the mission, may be suggested.

2. Development of the LRV Operations Design/Definition.

a. Sources for Development.

(1) Established constraints and interfaces from paragraph B. 1 above.

(2) Phase A report of vehicle Navigation and Guidance GDS concepts. Four vehicle navigation and guidance techniques have been hypothesized and used as bases for preliminary GDS concepts (Reference 1)

(3) Phase A report of science payload GDS concepts. This consists of a probable listing of experiments and a compatible GDS concept (present report)

(4) Phase A reports of operational organization and mission classes Two alternates of the former, and three of the latter are contained therein (present report and Reference 1)

b. Development Plan.

1) GDS.

(a) One or a mixture of the four Navigation/Guidance and Control concepts will be matched to the Phase B baseline concepts of Mission/LRV Navigation and Guidance. The four concepts have been defined to encompass a broad spectrum of probable designs so that all significant GDS factors have been considered.

(b) Similarly, the Science GDS concept will be matched to the Phase B experiment/payload concept.

(c) Items (a) and (b) above will be merged into a single detailed design. Operational capabilities dictated by items (a) and (b) which are redundant will be made to share a single capability.

(d) An addition to item (c) above will be due to general LRV "bus" considerations concerning performance analysis of such areas as power, thermal, telecommunications, and mechanisms.

2) Mission Operations Plan. The Mission Operations Plan will be derived primarily from and constrained by the Phase B baseline Mission Plan. It will reflect its interaction with and be iterated in development with the GDS, operations organization, vehicle, and science payload designs.

3) Operations Organization. The Phase B baseline organization will be established to implement the Mission Operations Plan (using the GDS design). Aspects of the organization will be developed as follows:

(a) A Navigation/Guidance/Science Payload Organization will be established using the more applicable aspects of the optional organizations contained in the Phase A reports

(b) An organization necessary to handle LRV performance analysis will be integrated with the above.

(c) A specification will be made of operational organizational interfaces with the DSN (mission-dependent organization) and the Manned Mission Organization.

3. Implementation.

The implementation plan which will be generated in connection with the Phase B effort will reflect a much more accurate picture than the implementation plan included here in the Phase A report. During Phase B, the narrowing of the four navigation and guidance techniques down to one finalized approach

along with the improved definition of the science payload should minimize duplication, thus allowing the preparation of a single feasible implementation plan. This plan will include a financial plan and schedules, and will outline the approach required for its realization.

C. WORK PLAN.

A work plan will be generated according to NASA requirements which will include but not be limited to consideration of the contractor interface, the resources allocation, schedules, reviews, and reports.

APPENDIX A
REFERENCES

1. Hornbrook, G. K., LRV Navigation and Guidance System, Phase A Study Report, Document 760-42 Jet Propulsion Laboratory, Pasadena, Calif., Oct. 10, 1969.

2. Burke, J. D. (Editor), A Study of Lunar Traverse Missions, Document 760-26. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 16, 1968.

3. Molloy, M W , Elements of Redirection for JPL Advanced Lunar Studies Team, NASA Letter MAL(MWM.ek) National Aeronautics and Space Administration, Washington, D C , Apr 25, 1969

4. A Dual Mode (Manned/Automated) Lunar Surface Roving Vehicle Design - Definition Study, Report DCN 1-9-21-00003. George C. Marshall Space Flight Center, Nov. 1, 1968.

5. Victor, W. K., DSN Capabilities and Plans, Volume III, DSN Data Systems Development Plan Mark III, Document 803-1 (Preliminary). Jet Propulsion Laboratory, Pasadena, Calif., July 9, 1969.

6. Hess, W. N., 1967 Summer Study of Lunar Science and Exploration, University of California, Santa Cruz, SP-157. National Aeronautics and Space Administration, Washington, D.C., July 31-Aug. 13, 1967.

7. Adams, J., et al., A Strategy for Scientific Exploration of the Terrestrial Planets, Document 900-28. Jet Propulsion Laboratory, Pasadena, Calif., July 12, 1967. Also published in Reviews of Geophysics, Aug. 1968.

8. Burke, J. D., Science Systems for Mobile Lunar Surface Exploration Preliminary Phase A Study Results, Document 760-36. Jet Propulsion Laboratory, Pasadena, Calif., June 2, 1969.

9. Phased Project Planning Guidelines, Handbook NHB 7121.2. National Aeronautics and Space Administration, Washington, D.C., Aug. 1968.

APPENDIX B
NOMENCLATURE

Mission Operations Complex - The aggregate of all Earth-based resources, including equipment, computer programs, personnel, procedures, and mission event sequences required for the conduct of mission operations.

Ground Data System - The aggregation of all physical equipment (hardware and software) providing ground operational support.

Mission Operations Organization - The organization comprising all personnel providing ground operational support.

Mission Operations Plan - (Reference only--not studied in this report.) The standard sequence of events and various nonstandard sequences of events, plus all operational procedures, operational interfaces, and countdowns governing the organizational elements comprising the Mission Operations Organization.

Science Ground Data System - That subset of the Ground Data System (GDS) which applies to science operations only.

Science Operations Organization - That subset of the Mission Operations Organization which applies to science operations only and contains no mission-independent elements.

Telemetry Data - (Reference only.) The data which contain (1) engineering information related to the performance and status of all vehicle elements including the camera portion of the science payload, (2) science information related to the on-board science instruments, and (3) video information, where video includes both image data and associated information such as frame count, line count, etc.

Command Data - (Reference only.) The data which contain (1) instructions generated within the MOC, which are ultimately transmitted to the vehicle as a means of executing desired functions, (2) information related to the confirmation of command instructions being transmitted to the vehicle relative to (1), and (3) information related to the verification of command instructions prior to its transmission to the vehicle.

Data Stream - That set of data flowing through a specified initial carrier.

Science Telemetry Data - Data emitted by the science instruments on the LRV and/or RGM and transmitted to Earth by telecommunications.

Science Data - Science telemetry data reflecting measurement of the lunar environment about the LRV and/or RGM and inherently one-dimensional in its nature.

Imaging Data - Science telemetry data reflecting measurement of the lunar environment about the LRV and/or RGM and inherently multi-dimensional in its nature.

Science Payload Engineering Data - Science telemetry data indicating the state or condition of the science instruments.

Science Command Data - Data generated within the MOC and ultimately transmitted to the LRV and RGMs to cause desired responses in the science equipment on board.

Manually Input Data - Data originated by humans and entered into the Data System by keying.

Outbound Command Data - Command data originated in the SFOF and transmitted in the direction toward the Moon.

Inbound Command Data - Command data for verification or confirmation purposes and transmitted in the direction towards the SFOF.

Data Functions:

Data Transmission, Acquisition, and Conversion - This function consists of all subfunctions associated with the changeover of RF or laser signals into digital data streams and vice versa.

Data Generation - This function consists of those subfunctions which are required to produce command and tracking data within the MOC.

Data Handling - This function consists of those subfunctions associated with the manipulation of data for the purpose of changing its format, but not its contents, for various purposes.

Data Processing - This function consists of those subfunctions associated with the manipulation of data for the purpose of changing its contents, e.g., the prediction of trends, analysis of performance, etc.

Data Display - This function consists of those subfunctions required for conveying of data-related information and selected data in human-readable form.

Data Selection - This function consists of those subfunctions associated with the establishment of alternate data modes and flow paths for various purposes, e.g., data processing, command data display and verifications, etc.

Vehicle (or spacecraft) - Any man-made body not on Earth. For the present mission this includes the LRV, the RGMs, and (if included) the Lunar Orbiter.

Alarm Condition - Evidence implying conditions at the instrument or in the data which are outside of prescribed limits.

Valid - Founded on truth or fact, correct.

Verification - Proof that issued commands have reached specified stations on Earth in valid condition.

Confirmation - Proof that issued commands reached the LRV in valid condition.

Instructions - Manually keyed input to the data system by the SOO, designating terminal accomplishments desired.

Command - A unit set of data transmitted to the LRV and/or RGM which are detected by the LRV and/or RGM and to which the LRV and/or RGM respond by altering their condition in a unit manner.

Command Sequences - Sets of commands in ordered sequence to accomplish a composite end not directly attainable by any single command.

Command Message - Any single-time issuance of a set of command sequences.

Supporting Research and Technology - All NASA research and technological development not funded by on-going projects.

Standard Operations - Pre-planned operations with a normally functioning LRV and its payload.

Nonstandard Operations - Operations in the presence of a suspected or confirmed anomaly in the LRV or its payload.

Screeding - Action of scraping particulate material from above the imaging plane of sample cups.

ACRONYMS

GDS	Ground Data System
LRV	Lunar Roving Vehicle. (The surface roving vehicle employed on the Moon for exploration.)
MDE	Mission-Dependent Equipment
MIE	Mission-Independent Equipment
MOC	Mission Operations Complex
MOO	Mission Operations Organization
MOP	Mission Operations Plan
RGM	Remote Geophysical Monitor. (Stationary scientific observing station.)
SCDS	Science Command Data Subsystem
SGDS	Science Ground Data System
SOO	Science Operations Organization
SRT	Supporting Research and Technology
STDS	Science Telemetry Data Subsystem

APPENDIX C
SCIENCE EXPERIMENTS

In this report, "experiments" are considered to be distinct from "instruments." Experiments are defined here as sets of operations conducted in order to determine facts which previously had been unknown. Instruments are defined here as the physical media and/or sensors by which experiments are conducted. Normally, experiments represent separate and individual fields of scientific investigation. Any one instrument can provide useful information to more than one experiment. Instruments constitute payload upon the vehicle, and instruments, as a class, do not include ground equipment.

The experiments taken as nominally standard for the purposes of this report were identified by Dr. R. G. Brereton of JPL's Advanced Studies Section and concurred in by Dr. L. D. Jaffe of JPL's Space Sciences Division. The instruments to perform these experiments were described jointly by Dr. Brereton and by Earle A. Howard of JPL's Lunar and Planetary Instruments Section and concurred in by Dr. Jaffe. The philosophy in these selections was:

(1) To present in the nominal standard lists that set of experiments and instruments considered to have the highest probability of being included in the actual mission.
(2) To supplement such standard lists by a listing of candidates which have high value but are excluded.

Objectives of the individual experiments are described here in paragraph B Operational aspects of the experiments are described in paragraph E of Section III, which identifies the instruments on the LRV, and in Appendix E, which outlines procedural techniques and data reduction, and shows the displays and operational decisions required

A. LIST OF EXPERIMENTS.

1. Nominal or High-Priority Experiments.

The principal or nominal science experiments foreseen at this time for the LRV are:

(a) Visual Terrain Assessment.
(b) Visual Examination of Samples.
(c) Mineral Phase Analysis.
(d) Chemical Element Analysis.
(e) Samples for Return to Earth.
(f) Magnetometry.
(g) Gravimetry.
(h) Earth-Distance Ranging.
(i) Soil Mechanics.
(j) Active Seismic Investigation.
(k) Remote Geophysical Monitors.

2. Possible or Low-Priority Experiments.

Experiments considered as possibilities for LRV but not included in the nominal set (1. above) for mission operations design study include

(a) Biological Studies.
(b) Fields and Particles.
(c) Atmospheric Investigations.
(d) Heat Flow.
(e) Select Spectral Studies.
(f) Radar and Microwave Investigations.

B. OBJECTIVES OF NOMINAL EXPERIMENTS.

The purposes or objectives of the nominal experiments for LRV are given below.

1. Visual Terrain Assessment.

(a) Perform (in situ) reconnaissance studies of the major geological features encountered in the traverse. Typically, such studies would include:

(1) Identification of major geological units (those of regional extent).
(2) Identification of minor geological units (dikes, sills, stocks, etc.).
(3) Location of contacts (interfaces) between geological units.
(4) Identification of fracture systems (faults and joints).
(5) Identification of geomorphic features (craters, domes, rilles, peaks, ranges, terraces, playas, etc.).
(6) Stratigraphic studies, where appropriate.
(7) Continuous search for evidences of volcanism and meteoritic impact.
(8) Continuous search for evidences of economic materials (moisture, permafrost, sulfur, other volcanic precipitates, etc.).
(9) Detailed visual investigation of unexpected or unusual geological features (shape, size, structure, macro-texture, etc.).
(10) Prediction of unscheduled impending needs for science operations for other experiments, deduced from visual study of the terrain (e.g., increased sampling rates as major contacts are approached).

(b) Create a topographic geological map of the visible terrain along the traverse route, augmenting and coordinating with pre-mission reference cartographic information, as required, for purposes of controlling, adjusting, identifying, and locating other scientific observations.

2. Visual Examination of Samples.*

(a) Determine the geological nature of the lunar material along the traverse by viewing individual specimens of such material at high magnification (fine resolution). For both soil and rock specimens, this includes such primary** observational factors as

(1) Heterogeneity (zonal discontinuities within specimen).
(2) Texture (size, shape, and inter-relationship of grains).
(3) Color (under various filters and polarization).

and such conclusions as

(4) Minerals present.
(5) Volumetric ratio of minerals present.

Properties to be observed which are peculiar to soil samples include·

(6) Consolidation.
(7) Cohesiveness.

Properties to be observed which are peculiar to rock samples include:

(8) Freshness of surface being observed.
(9) Rock type (basalt, granite, diorite, etc.).

*No distinction is made at this point between the terms "sample" and "specimen."

**Additional factors of geological interest which may be investigated in conjunction with visual imaging techniques include hardness, magnetic, and photometric properties.

(b) Determine the group characteristics of the specimens studied individually in B. 1 above:

(1) Statistical distribution of geological properties in the heterogeneous material at each sampling point.
(2) Spatial distribution of these properties along the traverse.
(3) Trends and projections.
(4) Major discontinuities.

(c) Apprise the Terrain Assessment observer of significant discontinuities encountered.

3. Mineral Phase Analysis.

(a) Determine the mineral phases present in the lunar material along the traverse route.
(b) Determine the group characteristics of the specimens studied individually in B. 1 and B. 2 above:

(1) Statistical distribution of mineral phases in the heterogeneous material at each sampling point.
(2) Spatial distribution of these properties along the traverse.
(3) Trends and projections.
(4) Major discontinuities.

(c) Apprise the Terrain observer of significant discontinuities encountered.

4. Chemical Element Analysis.

(a) Determine the elemental composition of the lunar material along the traverse route.

(b) Determine the group characteristics of the specimens studied individually in B. 1 and B. 2 above:

(1) Statistical distribution of elemental composition in the heterogeneous material at each sampling point.
(2) Spatial distribution of these properties along the traverse.
(3) Trends and projections.
(4) Major discontinuities.

(c) Apprise the Terrain observer of significant discontinuities encountered.

5. Samples for Return to Earth.

Assemble, identify, and deliver to the rendezvous site, for return to Earth by astronauts, that set of specimens of lunar material which will provide, within weight constraints, the greatest science yield.

6. Magnetometry.

(a) Map the lunar magnetic field (as a vector) along the traverse route.
(b) Locate and define major subsurface magnetic anomalies along the traverse route.
(c) Monitor the time-varying intensity of the lunar magnetic field during vehicle stops and hibernation.

7. Gravimetry.

(a) Map the anomalous components of the lunar gravitational field at the lunar surface, along the traverse route.
(b) Interpret the gravity anomalies in terms of probable subsurface structures.

(c) Provide fundamental measurement information on:

(1) Lunar isostasy
(2) Lunar crust.
(3) Lunar geodesy.
(4) Lunar geological features.

8. Earth-Distance Ranging.

(a) Provide increased accuracy in our ephemerides of lunar motion (physical libration and location of mass centroids).
(b) Measure time-varying deformation of the lunar crust, known as "tidal bulge effects."
(c) Define the size and shape of the Moon in the region of the arc of the traverse.
(d) Determine (in conjunction with the Gravimetry experiment) "frozen tidal effects."
(e) Provide, as redundant backup, information bearing upon the selenographic position of science sites.

9. Soil Mechanics.

Evaluate the soil-bearing properties of the lunar material along the traverse route.

10. Active Seismic Investigation.

Establish the depth, boundaries, and geophysical properties of the lunar regolith and subsurface at selected points along the traverse.

11. Remote Geophysical Monitors.

(a) Provide sustained scientific observations at fixed observing stations for such purposes as:

(1) Seismometry.

(2) Magnetometry.

(3) Astronomy.

(b) Provide local correction data for temporal variations in the lunar magnetic field at the LRV.

APPENDIX D
INSTRUMENTS

The manner of selection of the instruments designated herein as "nominal" for the LRV Mission was presented in the introductory remarks of Appendix C. The philosophy of presentation here parallels that in Appendix C, in that both the nominal complement of instruments and strong candidates not included in the nominal complement are listed. The principal functions of each instrument are then described.

In the interests of efficiency and the avoidance of unnecessary replication aboard the LRV, individual instruments must, in some cases, serve more than one experiment A table of such multiple-usages is shown at the end of this appendix (Table D-1).

A. HIGH-PRIORITY INSTRUMENTS.

The instruments assumed herein for the LRV Mission are·

(1) Panoramic TV Camera (facsimile).
(2) Foreground TV Camera (image dissector).
(3) Sample TV Camera (image dissector).
(4) Soil Sampler (scoop bucket).
(5) Rock Sampler (chipper/tongs)
(6) Soil Auger.
(7) Rock Core Drill.
(8) Sample Storage.
(9) X-Ray Diffractometer.
(10) X-Ray Spectrometer
(11) Vector Magnetometer.
(12) Gravimeter.
(13) Retroreflector.
(14) Seismic Charge Emplacer (and charges).

(15) Seismic Charge Detonator
(16) Seismic Sensor
(17) Remote Geophysical Monitors (RGMs).
(18) Inclinometer
(19) Gyroscope
(20) Laser Radar
(21) Penetrometer.
(22) Laser Range Finder

B LOW-PRIORITY INSTRUMENTS

Instruments which have been considered but are not included in the nominal list in paragraph A include (but are not limited to)

1 Instruments from Table III of Reference 2

(a) Petrographic Microscope
(b) Alpha Scatterer
(c) Gamma-Ray Spectrometer
(d) Magnetic Material Pickup Device
(e) Gamma-Gamma Backscatterer
(f) Gas Chromatograph.
(g) Mass Spectrometer
(h) Hygrometer
(i) Nuclear Magnetic Resonance Spectrometer
(j) 3-D Quadrupole Ion Gage (or Mass Spectrometer)

2 Additional Instruments from Reference 4

(a) Heat Flow Thermal Probe
(b) Geophysical Probe
(c) Drill (30 meters)
(d) Neutron-Gamma-Ray Analyzer
(e) Radar Reflectivity Probe.

(f) Electric Field Detector.
(g) Total Pressure Gage.
(h) Solar Wind Spectrometer.
(i) Charged Particle Detector

3. Additional Instruments Which Have Been Suggested Informally

(a) Radiometer.
(b) Hardness Scratch Set.
(c) Infrared Spectrometer.
(d) Electromagnetic Sounding Instrument
(e) Film Camera.

4. Biological Instruments.

(a) Aseptic Sampler
(b) Pyrolyzer (GCMS-DTA).

C. INSTRUMENT FUNCTIONS.

1. Panoramic TV Camera

(a) Provide detailed panoramic photo-imaging of the terrain surrounding LRV (360° x 60°, 1/3 mr x 1/3 mr, 4 bits, color)
(b) Provide photogrammetric measurement of the size, shape, and range of geological features of the terrain (baseline treated by vehicle motion).
(c) Provide photometric, colorimetric, and polarimetric measurements of selected regions of the terrain, to aid in differentiating observed features.
(d) Contribute to the production of topographic contour maps of the terrain zone which is visible from the LRV

(e) Observe lunar surface features at more than one angle of solar illumination and more than one look-azimuth, to assist in differentiating and correlating the visual information, identifying lunar features, and enhancing the accuracy of topographic measurements

(f) Observe time-variable phenomena taking place on the lunar surface, such as the formation of new craters by meteoroids, by successive observation of the same regions of the lunar landscape

(g) Support the Foreground TV Camera, both in the concurrent (simultaneous) dual operation mode and as a redundant backup in the event of failure (see Foreground TV Camera)

(h) Provide quick-look photo-imaging to monitor terrain being passed between secondary stations and to determine suitability of vehicle position for panoramic investigations

2 Foreground TV Camera

(a) Provide scan coverage of the immediate foreground selection of sample site and sample source

(b) Provide surveillance of condition, deployment, and motion of science instruments.

(c) Provide high resolution visual examination of rock samples

(d) Provide monitoring of storage and retrieval of samples

(e) Provide photogrammetric measurement of the size, shape, and position of features upon the lunar surface in the foreground by shifting the position of the camera with respect to the vehicle or by split images, using anaglyphic mirrors

(f) Provide definition of the geometric shape of the lunar surface itself, in the foreground, by shifting the position of the camera with respect to the vehicle or by using an anaglyphic-mirror split-image system

(g) Provide surveillance of near-field objects masked by the vehicle structure, e g , wheel sinkage, storage bin contents, sample screeding

3. Sample TV Camera.

(a) Provide high-resolution, color photo-imaging of soil samples presented by the Sample Storage System.
(b) Provide anaglyphic stereoscopic viewing of soil samples
(c) Provide photometry, colorimetry, and polarimetry of soil samples.
(d) Alter the natural illumination of such samples by means of adjustable mirrors, sample manipulation, or vehicle motion.

4. Soil Sampler.

(a) Acquire specimens of lunar material from loose, particulate soil containing rocks up to 3 cm in diameter and to input said specimen of soil into the Sample Storage System.
(b) Support the acquisition of rock samples too large for direct acquisition by the Soil Sampler by·

(1) Dislodging rocks from the matrix in which they are embedded by pulling them toward the LRV
(2) Recovering rock fragments produced by chipping when such chips are too small for efficient recovery by the tongs

(c) Test consolidation of the soil in compaction by pressing the broad surfaces of the scoop-bucket downward upon the soil
(d) Enable measurement of the deformation of the soil under known compressive steady-state force upon its surface.
(e) Test the consolidation of the soil under impact by driving the broad surfaces of the scoop-bucket dynamically into the ground
(f) Measure the time-varying force in (e) by means of a decelerometer
(g) Provide a means (spike on the head of the Soil Sampler scoop-bucket) of loosening semi-congealed particulate material in order that it can be scooped up by the bucket.

(h) Measure the existing consolidation of the soil by driving a spike into it, dynamically, and measuring (by means of accelerometers) the resistance to its penetration

(i) Indicate the cohesiveness of the soil by drawing the flat edge of the scoop bucket over the surface of the soil

(j) Indicate the cohesiveness of the soil by performing trenching, i.e., by digging a trench with free-standing walls.

(k) Provide calibrative check of the accuracy of the on-board laser at near distances by measuring the distance to foreground features through knowledge of the extension of the Sampler and its angle of elevation

5 Rock Sampler

(a) Acquire specimens of loose or fragmented lunar rock between 3 cm in diameter and 8 cm in diameter, and up to 15 cm in length, by prehension (picking up with tongs).

(b) Chip specimens from solid rock by striking the solid rock repeatedly with a chisel-like tool along a selected fracture line (trace of fracture surface).

(c) Present rock specimens, as in (a), to the Foreground TV Camera for geological inspection by high-resolution viewing, rotating the specimen upon command in order to present all parts of its surface

(d) Reposition the attitude of any one rock specimen within the tongs in order to present to the Foreground TV Camera polar areas not exposed by any one set of rotation of the tongs about its major arm

(e) Store rock specimens by placing them in the rock-storage bin or compartment (first placing them in container bags)

(f) Retrieve selected rock specimens from the rock-storage bin

(g) Transport seismic charges from their place of storage to the shot-hole

(h) Measure the resistance of lunar material to the penetration of the chisel under impact conditions

(i) Measure the resistance of lunar material to the quasi-static penetration of the tong points under force normal to the lunar surface

6 Soil Auger.

(a) Bring to the surface, for viewing in the ejecta heap and for acquisition by the Soil Sampler as samples to be viewed at high-resolution, loose or lightly coagulated material from short distances (1 meter) beneath the lunar surface.
(b) Enable logging of the stratigraphic nature of the material beneath the lunar surface for short depths (1 meter)
(c) Assist in the creation of shot-holes for active seismometry
(d) Measure the resistance of the soil to removal by Auger under the load applied along the Auger axis

7 Rock Core Drill.

(a) Acquire "undisturbed" specimens from bedrock or large rocks
(b) Acquire specimens of cohesive lunar material, having uniform, efficiently storable size and shape.
(c) Measure the resistance of the lunar material to the action of core drilling.

8. Sample Storage System

(a) Accept for storage, specimens of loose, particulate lunar material (from the Soil Sampler), cohesive or rocky material of specified size and shape (from the Rock Core Drill), and irregularly shaped rocky material (from the Rock Sampler).
(b) Present to the Sample TV Camera the top surface of soil specimens.
(c) Screed (draw a level bar across) the top surface of soil specimens before presentation to the camera and before withdrawal from the point of transfer from the Soil Sampler

(d) Tilt soil specimens selectively in two normal directions while being viewed

(e) Reject soil specimens upon command, leaving their former container available for further use and relatively free from contamination by carryover.

(f) Transport soil specimens from the transfer station to the analysis station at which x-ray analyses are performed

(g) Transport soil specimens from either the transfer station or the analysis station to individual storage stations

(h) Retrieve and transport soil specimens from their individual storage stations to either the analysis station or to a station at which they can be jettisoned

(i) Transport core samples from their loading station to permanent storage locations

(j) Retrieve and transport core samples from their permanent storage locations to a station at which they can be jettisoned

(k) Jettison core samples

(l) Encapsulate irregularly shaped rock samples (less than 8 cm in diameter by 15 cm in length) into individually labelled container bags

(m) Store encapsulated rock samples in retrievable fashion

9 X-Ray Diffractometer

The function of the X-Ray Diffractometer is to identify the types and relative abundance of mineral phases present in particulate specimens presented to it

10 X-Ray Spectrometer

The function of the X-Ray Spectrometer is to identify the elemental composition of particulate specimens presented to it

11. Vector Magnetometer

The function of the Vector Magnetometer is to measure the magnitude, direction, and time variation of the lunar magnetic field at the instrument

12. Gravimeter.

The function of the gravimeter is to measure the intensity of the gravitational field at the instrument

13. Retroreflector.

The function of the retroreflector is to reflect back to their individual sources, laser beams directed from Earth to the LRV.

14. RF Transponder

The function of the RF Transponder is to accept radio ranging signals sent from Earth-based tracking stations and transmit a corresponding return signal, with known time delay between reception and transmission.

15 Seismic Charge Emplacer

(a) Create the shot-hole in which seismic charges are to be placed
(b) Acquire seismic charges from their stowed position and emplace them in their shot-holes
(c) Back-fill and compact the back-fill after the charge has been placed.
(d) Check the operability of the detonation circuits.
(e) Arm the charge when ready.

16. Seismic Charge Detonator.

(a) Detonate emplaced charges, one at a time, in selected sequence.
(b) Provide a record of the time of detonation of each charge.

17 Seismic Sensor

(a) Detect the passage of seismic waves past the geophone

(b) Measure the time interval between charge detonation and arrival of first seismic waves at the Sensor

(c) Measure the time-varying character of the seismic waves

Table D-1. Use of Instruments to Support Experiments

EXPERIMENTS	INSTRUMENTS: PHOTO-IMAGING			SAMPLE ACQUISITION AND STORAGE					SAMPLE ANALYSIS		GEOPHYSICAL TRAVERSE INSTRUMENTS							JOINT USAGE (NAVIGATION/GUIDANCE AND SCIENCE)				
	PANORAMIC TV CAMERA	FOREGROUND TV CAMERA	SAMPLE TV CAMERA	SOIL SAMPLER	ROCK SAMPLER	SOIL AUGER	ROCK CORE DRILL	SAMPLE STORAGE	X-RAY DIFFRACTO-METER	X-RAY SPECTRO-METER	VECTOR MAGNETO-METER	GRAVIMETER	RETRO-REFLECTOR	SEISMIC CHARGE EMPLACER	SEISMIC CHARGE DETONATOR	SEISMIC SENSOR	REMOTE GEOPHYSICAL MONITORS	INCLINOMETER	GYROSCOPE	LASER RADAR	PENETROMETER	LASER RANGE FINDER
VISUAL TERRAIN ASSESSMENT	P	P	S	S	S	S	S		S	S								P	P	P		P
VISUAL EXAMINATION OF SAMPLES	P	P	P	P	P	P	P															
SAMPLES FOR RETURN TO EARTH	P	P	P	P	P	P	P	P	S	S												
MINERAL PHASE ANALYSIS		P	S	P	P	P	P		P	P												
CHEMICAL ELEMENT ANALYSIS		P	S	P	P	P	P		S	P												
GRAVIMETRY	S								S			P		S	S	S	P	S	S	S		S
MAGNETOMETRY									S		P	S		S	S	S	P			S		
SOIL MECHANICS		P	S	S	S	S	S		S												P	
ACTIVE SEISMOMETRY	S	S										S		P	P	P						
EARTH-DISTANCE RANGING	S	S											P				P					P
REMOTE GEOPHYSICAL MONITORS (CF- PARAGRAPH II C 2)																	P					

CODE
P = PRIMARY DEPENDANCE
S = SECONDARY DEPENDANCE

APPENDIX E
SCIENCE OPERATIONS

A INTRODUCTION.

In this appendix are listed the ground-system data processing, display, and command functions associated with each of the "nominal" experiments described in Appendix C Each description includes a summary of the scientific equipment on the LRV which is utilized in support of the experiment to be executed on the Moon, the data processing support required on Earth, the displays which are required on Earth for human monitoring and command/control of science operations, and the command decisions which must be reached

B OPERATIONS

1 Visual Terrain Assessment Experiment

a Instruments Employed

(1) Panoramic TV Camera
(2) Foreground TV Camera
(3) Laser Radar

b Procedural Technique

(1) Terrain assessment is based chiefly upon visual study of the landscape, supported by topographic contour maps, visual and x-ray analysis of specimens of lunar material, and geophysical findings.
(2) Imaging is assumed to be possible with the vehicle either moving or stopped, but detailed photo-imaging of the landscape is performed only while the vehicle is stationary. A few brief views between stops are taken at equal spacing along the traverse to achieve continuity in landscape recognition by interpolation.

(3) Photo-imaging at a science site is begun by a quick-look view of significant portions of the landscape Quick-look views are curtailed subsets of panoramic views at gross resolution [see (4) below] yielding reduced comprehension of the visible field but requiring only a fraction of the transmission time required by detailed photo-images The data of which they are composed constitute the first portion of a complete panoramic picture. They are used as a screening device to determine the suitability of the current site for expending the greater time required for full panoramic pictures and to determine optimal exposure conditions Decision is required regarding whether to continue the progress of photo-imaging at the current site or to adjust viewing conditions

(4) Following the quick-look view, the remainder of the panoramic view is recorded at standard resolution, transmitted, and displayed as a static view on a hemisphere (see d below) This display includes a grid of range and azimuth data based upon a "smooth surface" assumption. Geologists study the terrain and identify geological features in the terrain as to their location, nature, estimated scientific exploration value, and key elements of effort required to investigate Such information is fed directly into the data processing system The interpretation of the geological elements in the visible terrain will include consideration of the sample properties and geophysical findings in the area

(5) Concurrently with the panoramic imaging, distance to the objects in the field of view is measured by laser radar These data are reduced to a topographic contour map. The descriptive geological data from (4) above (exclusive of "effort" and "value") are annotated on this map

(6) A computer-based recommendation as to the order in which geological features should be studied is approved by the Acting Chief of Science Operations

(7) Geological features warranting photo-imaging investigation in greater detail (resolution) are then studied. Detailed photo-imaging of this kind is normally shown on planar displays The geological information deduced is fed into the data processing system.

(8) Execution of the plan for science operation may incur a dwell at the site until solar illumination angles reach specified values.

(9) The Visual Terrain Assessment Experiment may call for sampling to support its conclusions. Such sampling may be required at the current site or at sites displaced from the current site. To the maximum degree possible, such sampling will be specified predictively in the direction ahead of the vehicle rather than in the direction behind the vehicle, to save time by avoiding retrograde motion. The decision to undertake such sampling will be evaluated in (6) above

c Data Reduction.

(1) Total panorama pictures will be created by combining the quick-look video data with the remaining panorama video data.

(2) The specified grid of reference lines to be overlaid on the display of panorama, quick-look, and detail pictures will be generated by the computer. Grids will be "blankets" of azimuth-and-range and may, optionally, be based upon the assumption of a smooth, level surface or the actual topography [see (5) below].

(3) Geological data introduced into the data processing system by the geologists will be interpreted, combined with reference material, and stored for reference.

(4) The total of all geological features in the panorama which were identified in b (4) as potential candidates for further investigation are evaluated by computer, in conjunction with carry-over features identified at previous sites. Such evaluation adjusts the observer's estimate of scientific worth in

terms of standard catalogued values of specific features (if encountered), computes the impact of each candidate investigation (if undertaken) upon resources and constraints, ranks the candidates in order of the ratio of scientific value to expenditure of resources (time being a prime resource here), and identifies the cut-off below which features cannot be investigated without violating mission constraints.

(5) The laser radar range data will first be reduced to orthogonal components in the major selenographic coordinate directions. The contour-crossing points within each raster-line will be determined and contour lines faired through such contour-crossing points to form a topographic map. Geological annotations by the observing geologists [b.(4)] will be added.

(6) Changes in observed shadow lengths will be interpreted topographically.

d. Displays.

(1) The principal display for terrain assessment is the hemispherical panoramic display. This consists of viewing screens assembled in the approximate form of a hemisphere to represent the terrain panoramically, from the terrestrial horizon (which includes silhouetted terrain features projecting above the celestial horizon) down to the foreground. The viewer resides at the approximate center of hemisphere.

(2) Detailed photo-imaging need not be shown on curved surfaces but may be shown on planar surfaces.

(3) Topographic contour data will be shown graphically, as maps.

(4) Geological features observed will be annotated on above maps

(5) Changes in observed shadow length will be displayed on the hemispherical panoramic display.

e. Operations Decisions.

(1) Identification of next site for photo-imaging science operations.

(2) Suitability of an occupied site, as established through a quick-look picture, for extended photo-imaging operations
(3) Type of reference grid desired in displays.
(4) Detailed feature investigations to be conducted.

2. Visual Examination of Samples Experiment.

a. Instruments Employed.

(1) Soil Sampler (scoop bucket)
(2) Rock Sampler (chipper/tongs)
(3) Soil Auger
(4) Rock Core Drill
(5) Sample TV Camera
(6) Foreground TV Camera

b. Procedural Techniques.

(1) Under normal circumstances, all acquisitions of samples are performed within this experiment
(2) The general area (site) for sampling is normally designated in connection with the Visual Terrain Assessment Experiment.
(3) The specific location from which the specimen is to be drawn is determined within this experiment. To do this, the Foreground TV Camera is scanned over the ground immediately ahead of the vehicle and a selection made optically.
(4) For the operations which follow [see (5) below], the Foreground TV Camera is kept trained upon the outer or working end of all movable, deployable instruments, and the attitude, orientation, and foreground view of the Vehicle Simulator are kept slaved to the LRV.
(5) The particular acquisition instrument to be used in any given instance will depend upon the character of the material to be sampled. For surface samples of sandy material and small rocks, the Soil Sampler will be used. For subsurface samples in soil, the Soil Auger will be used. For loose rocks

too large to be accommodated in the bucket of the Soil Sampler, the Rock Sampler (tongs) will be used. For exposed rocks, when no loose fragments are available, the Rock Sampler (chipper) will be used to crack off specimens, which will then be retrieved by the tongs element of the Rock Sampler. For bedrock, when chipping is impractical, core samples will be obtained by drilling (Rock Core Drill), breakoff, and retrieval. The Rock Core Drill produces drillings, which are also retrieved.

(6) Samples picked up by the Soil Sampler are transferred to a sample cup, screeded,* and placed at the (fixed) sample viewing station for visual examination. Such samples are viewed by the Sample TV Camera, with the Stereo Attachment in place. The natural illumination is augmented by adjustment of mirrors or by reorientation of the LRV. The photoimaging data is viewed with a stereo-imaging viewer (anaglyph). The sample can be rotated to change the lighting. Focusing is essential.

(7) Samples acquired by the tongs are presented for inspection to the Foreground TV Camera, with its Stereo Attachment in place. The position for such inspection can be varied to obtain favorable lighting conditions. The specimen viewing attitude and cross lighting can be altered by rotating the Rock Sampler as a whole about its longitudinal axis. Viewing is done with an anaglyphic stereo-imaging device. Focusing is essential. The sample can be scratched on a set of standard hardness scratchers

(8) Visual properties of the specimens, determined by geological observers supported by optical assessment devices, will be fed into the data processing system.

(9) The decision as to whether the sample is to be rejected or to be passed on for other analyses or storage is made by comparing the visual and source-location properties of the sample

*Bar drawn across top

with those of prior samples. The sample is, accordingly, rejected or passed on to the next activity.

(10) Soil samples in sample cups are sent to the x-ray analysis station.

(11) Core samples are identified and placed in core sample storage

(12) Rock samples are identified and placed in bulk storage.

c. Data Reduction. All data from visual examination of samples are stored in the Sample Data Bank. Prominent within these is its source location and storage location.

d. Displays.

(1) Monoscopic photo-imaging of the sample.
(2) Stereoscopic photo-imaging of the sample.
(3) Tabulation of recorded observations.
(4) Vehicle Simulator.

e. Operational Decisions.

(1) Placement of acquisition instruments in acquiring samples.
(2) Control of instruments in acquiring samples (including transfer to sample cup).
(3) Control of cameras in viewing samples.
(4) Control of sample identification.
(5) Control of sample rejection/storage.

3. Samples for Return to Earth Experiment.

a. Instruments Employed.

(1) Direct Usage:

Sample Storage System

(2) Indirect Usage:

Sample TV Camera
Foreground TV Camera
Diffractometer
Spectrometer

b. Procedural Technique.

(1) This experiment selects sample sources, screens samples according to their properties, affixes identification, and stores samples. In acquiring and analyzing samples it utilizes instruments considered to be primary to other experiments.

(2) The intended plan for the acquisition and screening of samples under normal conditions is:

(a) The need for samples which arises from geological feature assessment will be identified by the Visual Terrain Assessment Experiment This is augmented by the pre-mission sampling plan and by the Sample Return Experiment's optimization of samples for return.

(b) The acquisition and visual examination of samples will be performed under the Visual Examination Experiment, which will recommend rejection or retention on the basis of visual properties.

(c) Samples which are retained from the Visual Examination Experiment will be analyzed under the Mineral Phase Analysis Experiment, which will recommend rejection or retention on the basis of mineral properties

(d) Samples which are retained from the Mineral Phase Analysis Experiment will be analyzed under the Chemical Elemental Analysis Experiment, which will recommend rejection or retention on the basis of chemical composition.

(e) Samples which are recommended for retention by all three analysis experiments are considered for storage,

comparing their total attributes (including source as well as physical properties), in competition with samples currently stored. The decision is made to reject the subject sample, store it in an available location, or to reject a currently stored sample and replace it with the subject sample.

(f) Rock samples chosen to be stored are given a physical identification before being stored.

(g) At the rendezvous with an astronaut, the entire assemblage of samples will be removed from the LRV by the astronaut and taken by him to Earth.

c. Data Reduction.

(1) All data concerning all samples will be stored in the Sample Data Bank.

(2) A computer recommendation of which samples to store will be made on the bases of the pre-mission sampling plan, the geological nature of the terrain traversed, the properties of the samples acquired, the availability of storage space, and the impact upon the vehicle's resources.

d. Displays.

(1) Foreground TV Camera image (stereo)
(2) Sample TV Camera image (stereo)
(3) Tabulation of visual properties and anomalies
(4) Diffractograms
(5) Tabulation of mineral properties and anomalies
(6) Spectrograms
(7) Tabulation of chemical composition and anomalies
(8) Catalog of stored specimens
(9) Rank order of specimen value

e. Operational Decisions.

(1) Selection of sample source
(2) Rejection/retention of samples
(3) Replacement of stored samples
(4) Identification of samples

4. Mineral Phase Analysis Experiment.

a. Instrument Employed. X-Ray Diffractometer.

b. Procedural Technique.

(1) A sample of lunar regolith material is first acquired, then transferred to a sample cup, and the sample cup is conveyed to the analysis station of the diffractometer. Only loose-soil samples are useful for this purpose.
(2) The instrument irradiates the specimen, measures the intensity of radiation diffracted at a specific angle, and reports this angle and its radiation level as primary data.
(3) The variation in radiation intensity with diffraction angle is then measured by scanning the desired range of diffraction angles mechanically. The rate at which such scanning progresses is remotely controllable. The reliability (resolution) of the data is enhanced by increasing the scanning time.
(4) After completion of the analysis, diffraction specimens can be either rejected or stored.
(5) Stored diffraction specimens can be retrieved and reanalyzed.
(6) A calibrated specimen may be carried for calibration purposes.
(7) The samples used for x-ray diffraction may also be used for optical microscopy.

c. Data Reduction. The conversion of diffractometry data into mineral phase data can be performed manually or by computer. The presence

or absence of candidate minerals in the specimen is established by the presence or absence in the specimen's diffractogram of that candidate mineral's characteristic diffraction pattern of radiation peaks as a function of diffraction angle. The relative abundance of minerals established to be present is reflected in the relative intensity levels in the diffraction peaks for such minerals. The number of candidate materials to be considered is reduced significantly by comparison with previously analyzed diffractograms. The mineral composition of the present specimen is to be compared versus (1) all specimens in storage and (2) the spatial trends and variance of all prior specimens, and significant coincidences and differences identified.

d. Displays.

(1) The diffractogram will be plotted as a graphic chart. Residual radiation not explainable in terms of the mineral phases present will also be shown.
(2) The identity and relative abundance of minerals concluded to be present in the specimen will be tabulated.
(3) The level of abundance of significant minerals and groups of minerals will be presented graphically as a function of the selenographic position of the specimens (roughly, as a traverse profile) and trends and variance shown.
(4) Anomalies in mineral composition will be tabulated showing the specimen source location, deviation from trend, and level of significance.

e. Operational Decisions.

(1) Rejection versus retention of specimen
(2) Future need for further analysis of specimen
(3) Need for additional specimens from this source
(4) Need for closer interval between specimen acquisitions ahead.

5 Chemical Element Analysis Experiment.

a. Instrument Employed. X-Ray Spectrometer.

b. Procedural Technique.

(1) A specimen of lunar material is acquired, transferred to a sample cup, and presented to the x-ray analysis station

(2) The instrument irradiates the specimen with a monochromatic beam of primary x-rays, measures the intensity and wave length of the emitted secondary radiation (fluorescence) that it stimulates, and reports, as primary data, this wave length and stimulated radiation which are characteristic of the composition and abundance of elements in the sample.

(3) The variation in radiant energy with wave length is then measured by scanning the desired range of wave lengths mechanically. The scanning rate is remotely controllable. The reliability of the data is enhanced by longer scanning time.

(4) After completion of analysis measurements, spectrometry specimens can be either rejected or stored.

(5) Stored spectrometry specimens can be retrieved and reanalyzed.

(6) A calibrated specimen may be carried for calibration purposes.

(7) The samples used for the X-Ray Spectrometer can also be used for the X-Ray Diffractometer and for visual examination.

c. Data Reduction. The conversion of spectrometry data into element data, through a process known as spectral analysis, can be performed manually or by computer The presence or absence of elements in the specimen is established by the presence or absence in the specimen's spectrogram of that element's characteristic pattern of radiant energy peaks. The fractional component of elements established to be present is a function of the relative intensity of spectrogram peaks for such elements The number of candidate elements to be considered is reduced significantly by comparison of the present specimen's spectrogram with previously analyzed spectrograms. The elemental composition of the present specimen is to be compared versus (1) all specimens in storage and (2) the spatial trends and variance of all prior specimens, and significant coincidences and differences identified.

d. Displays.

(1) The spectrogram (emitted radiation intensity versus incident wave length) will be plotted as a graphic chart. Residual radiation not explainable in terms of the chemical analysis concluded will be shown.

(2) The identity and abundance of elements concluded to be present in the specimen will be tabulated.

(3) The fractional composition of significant elements and groups of elements will be presented graphically as a function of the selenographic position of the specimens (roughly, as a traverse profile) and trends and variance shown.

(4) Anomalies in chemical composition will be tabulated, showing the specimen source location, deviation from trend, and level of significance.

e. Operational Decisions.

(1) Rejection versus retention of specimen

(2) Future need for further analysis of specimen

(3) Need for additional specimens from this source

(4) Need for closer interval between specimen acquisitions ahead.

6 Gravimetry Experiment.

a. Instruments Employed.

(1) Gravimeter

(2) Inclinometer

(3) Foreground TV Camera

(4) Odometer

(5) Accelerometers

(6) Gyroscope

b. Procedural Technique.

1) Gravimeter. The Gravimeter will normally be carried in the stowed position onboard the LRV. When a particular site and location for its deployment have been chosen, television monitoring by the Foreground TV Camera will be initiated and the Gravimeter will be unstowed and lowered to the ground The Gravimeter will be leveled and allowed to come to rest Its sensor will be uncaged The primary data readings will be taken The sensor will be caged The Gravimeter will be stowed

2) Inclination The Inclinometer reads out the pitch and roll of the LRV, which is equivalent to the slope of the ground along track and cross track Readout of the Gyroscope is continuous during translatory motion of the LRV and is interrupted during stops of the LRV

3) Foreground TV Camera. The Foreground TV Camera is kept automatically trained upon the Gravimeter during the period of the Gravimeter's motion during deployment and storage.

4) Survey Path. The survey path for gravimetric purposes is related to the geologic structures surveyed. The particular traverse for this purpose may be amended during the mission on the basis of field topographic information.

c. Data Reduction.

(1) Elevation and topography corrections to the direct readings of the Gravimeter must be calculated and deducted from the direct readings.

(2) The change in elevation of the vehicle will be determined by one or more of the following ways

(a) By integrating the ground surface slope over the traverse from the last point at which a topographic reference was obtained.

(b) By integrating on-board accelerometers

(c) By altimetry from Earth or lunar orbiters

(3) The local mass-irregularity factors at each site will be calculated from topographic data

(4) The radial distance from the centroid of the Moon to the LRV will be deduced from Earth-based laser and RF tracking data for the network of retroreflectors and transponders on the Moon, coupled with knowledge of the LRV's selenographic position from the Navigation and Guidance System.

d. Displays.

(1) Numerical values of the acceleration of gravity at the current site, as measured and as adjusted, together with the magnitudes of the corrections will be shown.

(2) The adjusted value of acceleration of gravity will be plotted as a map function of selenographic position and as a profile function of position along traverse.

(3) Elevation along the traverse will be shown as a profile function of position along traverse. Included will be the changes in elevation measured by the Inclinometer, the trace taken from the topographic map generated by laser, the trace taken from the reference topographic maps, and the locus of constant lunar centroidal distance established by Earth tracking.

(4) Vertical profiles through radial traces centered upon the vehicle's current position will be plotted as a function of radial distance from the vehicle, for selected azimuths.

e. Operational Decisions. Need for gravimetric surveys along paths normal to geological discontinuities will dictate, in some cases, the traverse route.

7 Magnetometry Experiment

a Instruments Employed

(1) Vector Magnetometer on board the LRV

(2) Vector Magnetometer on board the RGMs and other available reference sources (Apollo, etc)

b Procedural Technique All Magnetometers read automatically and continuously, reporting their data to Earth as functions of time No special placement of the vehicle is involved

c Data Reduction

(1) The direction and the intensity of the magnetic field at each instrument position, considered as functions of time, will be correlated.

(2) Anomalies in (1) will be detected and identified.

(3) The magnetic field at each instrument location will be resolved into its components parallel to the principal selenographic coordinate axes.

(4) A mathematical model will be fitted to the time-varying magnetic field at the reference Magnetometer stations (exclusive of the LRV) and the corresponding magnetic components at the LRV established by interpolation.

(5) The spatial-variation component of the magnetic field at the LRV will be computed by deducting from the total directly observed value at the LRV the value interpolated from the time-varying lunar magnetic field [cf (4) above]

(6) The spatial-variation component of the magnetic field at the LRV will be established as a function of selenographic coordinate position and anomalies identified

(7) The effective center of the attraction producing each observed magnetic anomaly will be determined, both as to selenographic coordinate position and as to magnitude of source

d Displays

(1) The variation of directly measured magnetic field intensity and direction will be plotted as functions of time for each Magnetometer

(2) The correlation between pairs of the separate plots in (1) will be plotted as functions of time

(3) Anomalies in (1) and (2) will be indicated by pointers on the plots

(4) The selenographic coordinate components of the magnetic field at each Magnetometer will be plotted as functions of time

(5) The spatial variation in magnetic field intensity (observed LRV components minus interpolated reference components) will be plotted as a function of selenographic position (roughly, as a function of distance along traverse)

(6) Magnetic anomalies will be plotted in a vertical profile along the traverse

e Operational Decisions No operational decisions are expected to be based upon Magnetometer data

f General. Note that the LRV Magnetometer, operating while the LRV is stationary, will measure the time-varying component of the lunar magnetic field at the LRV

8 Soil Mechanics Experiment

a Instruments Employed

(1) Penetrometer

(2) Soil Sampler

(3) Foreground TV Camera

(4) Sample TV Camera

b Procedural Techniques

(1) The readings of the Penetrometer taken by the Guidance System (Reference 1) as a means of hazard detection will be interpreted as a measure of the bearing strength of the soil.

(2) The Soil Sampler will be pressed statically against the soil and the resulting displacement correlated with the applied force and bearing area. Displacement will be estimated from television monitoring. Force will be measured through drive motor currents and force transducers, e.g., strain gages The bearing area will be dependent upon the particular face of the Sampler which is presented to the soil (the back, the jaw, the spike, etc.).

(3) The Soil Sampler will be raised above the soil and allowed to drop (free fall plus driving force) against the soil. The deceleration will be measured by means of an accelerometer attached to the Soil Sampler. The contact area will be dependent upon the particular face of the Sampler which is presented to the soil.

(4) The Soil Sampler will be dragged along the surface and the soil resistance force determined by the drive motor currents and force transducers. Velocity of the Sampler will be measured by position transducers giving the articulation of the Sampler. Soil condition will be viewed through the Foreground TV Camera.

(5) Trenching will be performed by the Soil Sampler and the forces measured. Soil cohesion will be assessed by the slope of the trench walls, using the Foreground TV Camera.

(6) The chisel of the rock sampler will be forced into lunar regolith material and its critical thrust (producing perceptible penetration) measured, with penetration evidenced by the Foreground TV Camera.

(7) Cohesiveness of the soil will be determined from visual examination of screeded soil samples, using the Sample TV Camera.

(8) Settlement or sinkage of the vehicle's wheels as the vehicle advances (by a partial revolution of the wheels) will be viewed directly by pointing the Foreground TV Camera at the wheel contact zone.

(9) The residual visible track left by the vehicle will be viewed by the Foreground TV Camera.

(10) No special placement of the vehicle for soil mechanics purposes is assumed.

c. Data Reduction.

(1) Bearing strength of the soil will be a directly calibrated function of Penetrometer reading. The trend and variance in this property will be computed.

(2) The unit static pressure under the Soil Sampler, as determined from calibrated force measurements and the known presented area, will be correlated with measured displacement and the bearing strength established from discontinuity in this relation.

(3) The velocity at impact will be determined by integration of the acceleration. The unit force and the penetration during deceleration will be determined from the deceleration and the known presented area.

(4) Velocity of the sampler parallel to the soil surface will be determined by the position transducer records.

(5) The bearing strength as determined by (2) and (3) will be correlated with that in (1).

d. Displays.

(1) The readings of the Penetrometer and the bearing strength per c.(2) and c.(3) will be plotted as profile functions of position in traverse. The trend line and variance bands of each will be superimposed.

(2) Settlement of the Soil Sampler under static load will be plotted as a function of the load and the breakpoint indicated.

(3) The unit force during impact deceleration will be plotted as a function of penetration distance.

(4) The drag force in the Sampler as it is drawn over the surface will be plotted as a function of its velocity.

(5) The ratios of static bearing strength and dynamic bearing strength to the calibrated bearing strength indicated by the Penetrometer will be plotted as a profile function of position in traverse.

(6) The resistance encountered by the chisel of the rock sampler will be shown numerically.

(7) The photo-imaging of the Foreground and Sample TV Camera will be displayed.

e. Operational Decisions. No operational decisions due to soil mechanics are introduced by the Science Ground Data System and Operations Organization. (This responsibility is assigned to the Navigation and Guidance Ground Data System and Operations Organization.)

9. Active Seismometry Experiment.

a. Instruments Employed.

(1) Seismic Charge Emplacer
(2) Seismic Charges
(3) Seismic Sensors
(4) Seismic Detonator
(5) Soil Auger

b. Procedural Technique.

(1) The specific location for active seismic experiments will be decided from the combination of pre-mission reference information (topographic) and geological terrain assessment during the mission.

(2) The plan for relative numbers of Charges versus Sensors for the LRV Mission differs from common practice in terrestrial seismic investigation. In the LRV Mission, only one Sensor is provided. The number of Charges per Sensor location may be one or more. A specific plan for the distribution of Charges to investigate any given area seismically will be generated during the mission.

(3) For each Charge the vehicle will be moved to its selected site and the specific location for emplacing the Charge selected by Foreground TV Camera inspection of the local site.

(4) Depending upon the design ultimately chosen for the Emplacer, the shot-hole for the Charge may be drilled by the Soil Auger. If it is, the procedure followed will be that described in E. 3, Visual Examination of Samples Experiment.

(5) Motion of the deployable instruments will be monitored at all times by the Foreground TV Camera.

(6) The Seismic Charge Emplacer will be deployed to the ground and placed in the shot-hole.

(7) The Seismic Charge will be deployed to and placed in the Seismic Charge Emplacer.

(8) The Seismic Charge Emplacer will be withdrawn and stowed.

(9) The shot-hole will be backfilled by scraping the Soil Auger ejecta into it, using the Soil Sampler.

(10) The Seismic Charge will be armed, for example, by mechanically pulling a lanyard left trailing out of the shot-hole.

(11) The LRV will be backed away from the shot-hole, to the next shot-hole or to the Sensor location.

(12) The Sensor specific location will be selected by Foreground TV Camera inspection of the local site.

(13) The Sensor location will be cleared of debris and loose soil to a reasonable depth.

(14) The Seismic Sensor will be deployed to the assigned spot.

(15) The Seismic Sensor will be pressed into position by the Soil Sampler.

(16) The Seismic Sensor will be uncaged.

(17) The Seismic Charges will be detonated one at a time, by means of a radio signal from the Seismic Charge Detonator. Record of transmission of this signal will simultaneously be telemetered to Earth.

(18) The arrival time of the seismic-wave leading element will be telemetered to Earth.

(19) The intensity of the seismic disturbance, as a function of time, will be telemetered to Earth.

(20) The Seismic Sensor will be caged and stowed.

(21) Introductory measurement of the velocity of seismic waves in the regolith is required, prior to more extensive subsurface investigations.

c. Data Reduction.

(1) Time differences between detonation and arrival of seismic wave are computed.

(2) Distances between the shot-holes and Sensor location are computed.

(3) Regolith depth is interpreted as a function of distance per (2), and of wave travel times per (1).

d. Displays.

(1) The wave travel time from shot-hole to Sensor is plotted as a function of their horizontal separation.

(2) Regolith depth is plotted as a profile function of the traverse and is shown as a contour map function.

e. Operational Decisions.

(1) The choice of locations for shot-holes and Sensors.

(2) The commands incident to the operations described in 10. b

10. Earth-Distance Ranging Experiment.

a. Instruments Employed.

(1) Earth-based laser
(2) Earth-based RF tracking system
(3) Retroreflectors on LRV and Remote Geophysical Monitors
(4) RF Transponder on LRV and Remote Geophysical Monitors

b. Procedural Techniques.

(1) All RF tracking techniques will follow present practice.
(2) Acquisition of laser tracking (successful pointing of transmitter and receiver) will be achieved by search procedures.

c. Data Reduction.

(1) Search techniques for laser acquisition
(2) RF data reduction
(3) Laser data reduction
(4) Tracking station network dimensions determination.
(5) Moon orbit and libration determination
(6) Lunar station network position relative to selenographic coordinate system
(7) Change in lunar station network with time
(8) Change in LRV position with time.

d. Displays.

(1) Laser search pattern (plot)
(2) Pseudo-residuals plotted as functions of time
(3) Tracking station network adjusted dimensions (tabular)
(4) Moon orbit and libration parameters (tabular)

(5) Lunar network secular changes (tabular)

(6) LRV change in position with time (plot)

e. Operational Decisions. No operational decisions are based upon the Earth-Distance Ranging Experiment.

f. General Note. Execution of the Earth-Distance Ranging Experiment belongs properly within the Science Tracking Data Subsystem and will be studied in Phase B.

11. Remote Geophysical Monitor (RGM) Experiment.

a Instruments Employed.

(1) Magnetometer

(2) Gravimeter

(3) Passive Seismometer (assuming lunar natural seismic activity is sufficient to make experiment worthwhile)

(4) Retroreflector

(5) RF Transponder

b. Procedural Technique.

(1) The RGMs will be carried to their operational sites by the LRV, will be deployed by the LRV, oriented by the LRV, and adjusted by the LRV.

(2) All activities involving physical motion of the RGMs (apart from their transport to the site by the LRV) will be monitored by the Foreground TV Camera.

(3) The location for the RGM will be scraped clear of debris and loose soil, by the Soil Sampler, prior to deployment of the RGM.

(4) Orientation includes alignment with respect to both the Moon-Earth axis and the local direction of selenographic north.

(5) Readings of LRV-borne instruments corresponding to RGM-borne instruments will be taken for calibration before the LRV leaves the RGM site.

(6) The Magnetometer, Gravimeter, and Seismometer produce data spontaneously on a timed cycle. The Transponder transmits a response to RF tracking signals it receives. The retroreflector causes specular return of light signals.

(7) Seismic data sensed passively by the Seismometer are stored on board for delayed transmission. Magnetometer and Gravimeter data are transmitted directly, without storage.

(8) The RGM telemeters automatically from Moon to Earth the data output by RGM instruments.

(9) At least one single active-seismic measurement, using a relatively short Charge-to-Sensor distance, will be made at each RGM for the purpose of calibrating the seismic velocity in that region.

c. Data Reduction.

(1) Magnetometer data will be reduced as described in E. 8, Magnetometry Experiment.

(2) Gravimeter data will be reduced as described in E. 7, Gravimetry Experiment.

(3) Seismometer data, which consist of the magnitude of the Seismometer Sensor output as a function of time and which were stored on board the LRV at the time of their occurrence and played out later, will be converted into epicentric distances. The selenographic position of the epicenter will be determined from the combined seismic data of the set of deployed RGMs including multiple-globe-circling recurrences of the strong seismic waves

(4) The velocity of seismic surface waves will be confirmed by the recurrent passage of strong waves circling the Moon and repassing the Seismometer

(5) The Retroreflector and Transponder do not involve data reduction.

d. Displays.

(1) Magnetometry displays are described in E. 8
(2) Gravimetry displays are described in E. 7.
(3) The time of arrival of seismic waves at each RGM and the associated epicentric distance will be tabulated.
(4) The magnitude of the passive Seismometer reading at each RGM will be plotted as a function of time.
(5) The magnitude of successive recurrent seismograms will be superimposed by offsetting each one by the amount of its time of travel around the globe.

e. Operational Decisions. No operational decisions are dependent upon RGM data.

f General Note Execution of portions of this experiment belongs properly to the Science Tracking Data Subsystem, which is one of the "Other Science Data Subsystems" identified in Figure 3-2 Execution of the Earth-Distance Ranging Experiment is not discussed in this report (Phase A) but will be treated in the Phase B study

APPENDIX F
TEST CLASSIFICATIONS

Five basic test classifications have been established to demonstrate that the Mission Operations Complex (MOC) consists of properly functioning and integrated elements operated by personnel adequately trained for their operational roles The following paragraphs describe these five classifications

A ENGINEERING TESTS.

Engineering tests are to demonstrate that all elements of the MOC meet the design specifications and functional requirements. They may range in scope from single-element tests to those encompassing inter-facility tests. The prime objective is to detect design deficiencies, areas of poor reliability, and incompatible interfaces. In order to assure compliance with such a range of test requirements, three types of Engineering Tests shall be conducted.

1. Engineering Design Verification Tests

These are single-element tests to verify that the element is operable and meets its design requirements as a separate entity.

2. DSN Engineering Acceptance Tests

These tests verify that all mission-dependent elements are physically compatible with the GDS.

3. Engineering Integration Tests

These tests verify the engineering compatibility of the element with the GDS and may include the exercise of entire facilities and combinations of facilities comprising the GDS.

B COMPATIBILITY TESTS

These tests verify that the Flight Operations Organization, using the GDS and the Flight Operations Plan, can receive, process, and display vehicle data and formulate, encode, and transmit commands to the vehicle and produce the desired vehicle activity

C LOCAL OPERATIONAL TRAINING TESTS

These tests verify that the operational personnel within any facility are prepared for performing their operational assignments The tests not only train and increase the proficiency of the operating personnel but also verify the adequacy of the operational procedures

D FUNCTIONAL PERFORMANCE ACCEPTANCE TESTS

These tests are designed to demonstrate that the functional performance of the various subsystems of the MOC meets the requirements of the operational user. These tests are inter-facility in scope since elements of the subsystem under test are always located at the place where space flight operations are exercised and one or more of the DSN facilities The operational procedures are to be used to the greatest extent possible

E INTER-FACILITY OPERATIONAL TRAINING AND READINESS TESTS

The inter-facility training tests are designed to increase the operational proficiency of the MOC personnel and are performed when all other tests have been completed The culmination of the inter-facility training tests is the final operational readiness test Its successful completion demonstrates that the elements of the MOC are properly integrated and ready for optimum performance in support of the mission